

Effects of DDT Spraying for Spruce Budworm on Fish in the Yellowstone River System

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ABSTRACT

DDT was sprayed at 1 pound per acre from airplanes for the control of spruce budworm on 71,678 acres in the Yellowstone River drainage in 1957. Stream-bottom invertebrates were reduced in number immediately after the spray. Recovery to near-normal total numbers occurred within a year in most streams, but species composition was altered. Drift samples in one stream showed dead and dying invertebrates to be drifting in the current in great numbers. No mortality to fish was found. Chemical analysis showed that DDT up to 0.03 p.p.m. was in several samples of water from streams. In one case a trace was found 55 miles downstream from the spray area. Vegetation samples contained up to 2.3 p.p.m. of DDT. All of the 80 samples of mountain whitefish (*Prosopium williamsoni*) and rainbow and brown trout (*Salmo gairdneri* and *S. trutta*) analyzed contained either DDT up to 14.0 p.p.m. or DDE up to 6.53 p.p.m., or both. DDT was found in trout 85 miles below the spray area, and fish taken more than 2 years after spraying contained DDT.

INTRODUCTION

Widespread mortality among mountain whitefish (*Prosopium williamsoni*), brown trout (*Salmo trutta*), and longnose suckers (*Catostomus catostomus*) in the Yellowstone River below Yellowstone National Park attracted the attention of sportsmen and biologists in the fall of 1955. Thousands of dead fish were seen in the Yellowstone River from October to December, and it was concluded that this mortality must be related to the spruce-budworm spray program that had been conducted in the Yellowstone River drainage during the previous July. Fish studies had been made in connection with this spray, but it was not possible to ascertain the role of DDT spray in the destruction of fish. Some sections of aquatic invertebrates had been collected before and after spraying in streams in the spray area, and these indicated drastic reductions in invertebrate populations took place immediately after the spraying of DDT.¹

Cope, Oliver B., and Donald E. Parker. (1956) Study of conditions attending fish mortalities in Yellowstone River following spruce budworm spray program. Report issued by the U. S. Forest Service, August 1956, 9 pp. + appendices.

Plans for spraying an additional 70,000 acres in the Yellowstone drainage were drawn up by the National Park Service and the Forest Service in the spring of 1957. The spray for control of spruce budworm with DDT was scheduled for June and July of 1957 in areas within Yellowstone National Park. This program provided an opportunity to make studies on the effects of the spray on fish and fish-food organisms in the area. Funds for the study were provided by the U. S. National Park Service, the U. S. Forest Service, and the U. S. Fish and Wildlife Service. The Fish and Wildlife Service performed the field work, and the Chemistry Department at Montana State College at Bozeman, Montana, and the Wisconsin Alumni Research Foundation did chemical analyses on materials exposed to DDT.

DESCRIPTION OF THE AREA

The area affected by the 1957 spray program in Yellowstone National Park is in the Yellowstone River drainage in the northern portion of the park and downstream for 65 miles outside the park (Figure 1). The terrain is mountainous, with tributaries draining from altitudes over 9,000 feet into the Lamar River at 6,000-6,500 feet and into the Yellow-

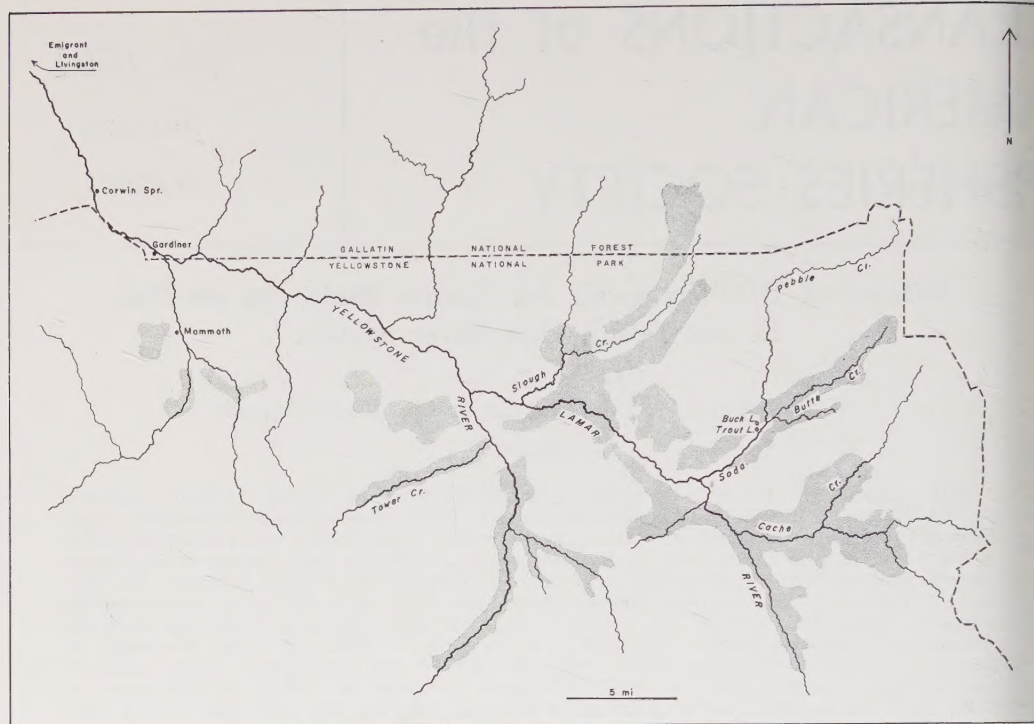


FIGURE 1.—Spray areas in Yellowstone National Park—1957.

stone River at 6,000–7,000 feet above sea level. The higher elevations are above timber line. Pines and Douglas fir cover much of the area above the valley floors. The broad valleys of the Yellowstone and Lamar are open along most of their floors, but forest trees grow close to the water in a few isolated patches. The wide valley floor of the Yellowstone River outside the park is covered with sagebrush, except in the Yankee Jim Canyon area which has sagebrush and sparse Douglas fir close to the water for a few miles.

The tributary streams all have steep gradients along most of their courses. The Lamar and Yellowstone Rivers have very fast currents during flood stage, but even at low water there is sufficient turbulence to cause a constant mixing of waters. Alkalinity, turbidity, and temperature of the streams vary considerably (Table 1). The Lamar contains a small amount of aquatic vegetation; the Yellowstone has more. The fish fauna of the Lamar consists of cutthroat trout (*Salmo clarki*), longnose sucker, and longnose dace (*Rhinichthys cataractae*), with a few rainbow trout (*Salmo gairdneri*) and mountain whitefish. The Yellowstone River contains the same

fauna plus brown trout. Some tributaries the Lamar and Yellowstone Rivers are rich aquatic invertebrates used as food by fish. The Lamar River itself is only moderately rich aquatic invertebrates, but the Yellowstone contains an abundance of animal fish food. few small lakes are located within the area. They contain cutthroat and rainbow trout and have abundant rooted aquatic vegetation.

THE SPRAY OPERATION

The 1957 spray operation began on July 1 and terminated on July 21 (Table 2). The area sprayed consisted of 71,678 acres on six plots (Figure 1). Spraying was done from aircraft under a set of standards designed to minimize the deposition of spray on water surfaces. The toxicant was DDT, applied in an oil solution at the rate of 1 pound per acre. The average amount of DDT reaching the ground on six plots was 0.18 pound per acre as measured by spray cards distributed to U. S. Forest Service entomologists.

METHODS

The general plan for the field study called for samples and measurements taken 1 week

TABLE 1.—Physical and chemical characteristics of sampled waters, 1957

Stream and date	Total alkalinity ¹ (p.p.m.)	pH	Water temperature (°F.)	Stream flow (c.f.s.)	Turbidity
Creek (above falls)—July 7	30	7.2	66 (10:25 a.m.)	134	Low
Creek (near mouth)—July 7	34	7.25	44 (12:10 p.m.)	840	Low
Butte Creek (below Pebble Creek)—July 7	54	7.5	52 (1:55 p.m.)	312	Moderate
Lake outlet—July 7	119	8.0	60 (1:40 p.m.)	10	Low
River (below Slough Creek)—July 7	37	7.8	44 (11:30 a.m.)	1,584	High
Yellowstone River (Corwin Springs)—July 3	41	7.8	58 (3:00 p.m.)	5,500	High

¹ phenolphthalein alkalinity was found in any samples.

prior to spray time, and post-spray samples and measurements taken at intervals during the treatment. Numbers of stream-invertebrate organisms were determined before and after the spray operation. Samples of water from streams and lakes, samples of fish, and samples of aquatic vegetation for analysis of DDT content were taken throughout 1957 and during 1958 and 1959.

The principal collecting stations were located at:

Tower Creek—50 yards upstream from a point opposite the Tower Falls campground;

Lamar River—100 yards upstream from the Cook City Highway Bridge;

Slough Creek—20 yards upstream from the mouth of Buffalo Creek and 100 yards upstream from the mouth of Slough Creek;

Soda Butte Creek—opposite a point 100

yards downstream from the "The Thunderer" sign on the Cook City Highway; Trout Lake outlet—50 yards downstream from the dam at the outlet;

Trout Lake—east shore of Trout Lake, near the outlet;

Yellowstone River, Corwin Springs—200 yards upstream from the steel bridge at Corwin Springs, 6 miles downstream from Gardiner, Montana;

Yellowstone River, Emigrant—100 yards upstream from Yellowstone River bridge at Emigrant, Montana; and

Yellowstone River, Livingston—50 yards downstream from Yellowstone River bridge, 5 miles upstream from Livingston.

Fish

Collections of fish in affected waters were made near collecting stations and in most tributary streams in the Lamar River, in the

TABLE 2.—Spruce-budworm spraying schedule during July 1957 in the Yellowstone River basin

	Area (acres)	Gallons of spray	Pounds per acre		Unit sprayed
			Sprayed	Reaching ground	
	1,607	1,876	1.17	—	Bunsen Portion and Lava Creek Portion
	1,395	1,350	0.96	—	Mammoth Hot Springs, Cloggett Butte
	1,690	1,582	0.93	—	Oxbow-Geode, south of old road
	2,685	2,690	1.00	—	Crescent Hill-Tower Fall
	598	560	0.93	—	Deep Creek
	2,055	2,061	1.00	—	Tower Creek
	7,045	4,601	0.65	—	Yellowstone Canyon
	2,688	2,669	0.99	0.26	Specimen Ridge-Jasper Creek
	3,260	2,875	0.88	—	Slough Creek-Lamar River Canyon
	3,265	2,100	0.64	—	Buffalo Creek
	638	525	0.82	—	McBride Lake
	3,880	3,755	0.96	—	West Slough Creek
	1,973	1,500	0.76	—	East Slough Creek—lower
	3,143	2,700	0.85	—	East Slough Creek—upper
	2,593	2,575	0.99	0.40	Rose Creek
	2,195	2,200	1.00	—	Chalcedony Creek
	2,752	2,701	0.98	0.24	Soda Butte
	1,075	1,030	0.96	0.13	Trout Lake
	3,113	3,200	1.03	0.03	Druid Peak
	2,360	2,500	1.05	—	Soda Butte-Amphitheater Creek
18	6,155	6,501	1.06	0.11	Northeast Entrance Road
21	4,048	4,043	1.00	—	Lower Cache Creek
21	3,600	3,677	1.02	—	Lamar River
	3,742	3,500	0.93	—	South Cache Creek
	4,123	3,900	0.94	—	Upper Cache Creek
Overall average	71,678	66,671	0.93	—	—

TABLE 3.—DDT and DDE contents of trout collected from the Yellowstone River drainage in 1957, 1958, and 1959

Locality	Species	Date collected	DDT content (p.p.m.)	DDE content (p.p.m.)
Trout Lake	Rainbow	7-30-57	4.9	0.7
Buck Lake	Cutthroat	9-13-57	6.7	1.2
	Cutthroat	9-20-57	5.76	1.26
	Cutthroat	9-22-57	5.1	0.0
	Cutthroat	10-19-57	5.00	—
	Cutthroat	6-27-58	2.10	—
	Cutthroat	8-16-58	0.51	1.90
	Cutthroat	6-16-59	1.18	0.85
Soda Butte Creek	Cutthroat	6-29-58	1.12	—
	Cutthroat	7-27-58	1.09	0.15
Cache Creek	Cutthroat	8- 9-57	14.0	1.6
Lamar River	Cutthroat	8- 9-57	4.2	1.0
	Cutthroat	8-14-57	11.0	3.2
	Cutthroat	9- 4-57	1.8	0.60
	Cutthroat	1-17-58	6.94	—
	Cutthroat	6-26-58	5.04	—
	Cutthroat	8- 5-58	0.85	0.99
	Cutthroat	6-19-59	1.03	0.90
Slough Creek	Rainbow	7-19-57	2.01	0.77
	Rainbow	8- 9-57	10.2	2.5
	Cutthroat	12-11-57	0.44	—
	Rainbow	6-28-58	1.04	—
	Cutthroat	8- 2-58	0.20	1.29
Yellowstone River between Geode and Hellroaring Creek	Cutthroat	8-11-57	0.74	—
Above Yancey's Hole	Rainbow	8-10-57	1.20	—
Above Gardiner	Cutthroat	6-25-58	0.45	—
	Brown	6-28-58	1.09	—
Gardiner	Brown	1-18-58	1.38	6.53
	Brown	7-30-58	0.91	3.74
	Cutthroat	7-30-58	0.37	1.21
	Rainbow	7-30-59	0.38	0.44
Corwin Springs	Brown	8- 3-57	1.1	0.5
	Brown	8-11-57	1.2	0.9
	Cutthroat	8-11-57	2.1	0.2
	Cutthroat	12- 9-59	0.9	—
Emigrant	Cutthroat,			
	rainbow	8- 3-57	1.4	0.69
	Cutthroat	9-25-57	0.9	0.2
	Brown	9-13-57	1.4	0.7
	Brown	9-13-57	0.4	0.0
	Rainbow	9-13-57	0.6	0.05
	Rainbow	9-13-57	1.6	0.05
	Rainbow	9-25-57	0.9	0.1
	Brown	6-21-58	0.56	—
	Rainbow	6-21-58	0.21	—
	Cutthroat	6-21-58	0.18	—
	Rainbow	7-17-58	0.22	0.21
	Brown	7-17-58	0.60	2.79
	Rainbow	8-23-58	0.20	0.40
	Brown	8-18-58	0.62	1.49
	Rainbow	6-19-59	0.68	0.36
	Rainbow	6-20-59	0.24	0.21
Livingston	Rainbow	8-19-57	1.2	0.01
	Brown	8-19-57	1.9	0.4
	Rainbow	10- 9-57	0.13	—
	Brown	10- 9-57	0.76	—
	Brown	11-12-57	1.23	—

Yellowstone River near Emigrant and near Livingston, and in Buck Lake. Fish were collected by shocking and by angling. During 1957 collections were made, whenever possible, before spraying and at 1- to 3-week intervals after spraying. Samples were obtained whenever possible in 1958 and 1959. Fish were frozen for preservation and stored in polyethylene bags. Samples analyzed included

rainbow, brown, and cutthroat trout, moun whitefish, and longnose dace. Most fish samples were about 1 pound in weight. The whole fish were ground and blended and then analyzed for DDT and DDE by the Schechter-Haller method (Schechter and Haller, 194

Water

Water samples were collected before and after spraying. Collections were made in n

TABLE 4.—DDT and DDE contents of mountain whitefish collected from the Yellowstone River in 1957, 1958, and 1959

Locality	Date collected	DDT content (p.p.m.)	DDE content (p.p.m.)
Emigrant	July 30, 1958	0.62	2.14
	June 17, 1959	1.42	0.15
	Aug. 6, 1957	3.3	0.2
	Aug. 11, 1957	0.06	0.02
	Aug. 11, 1957	2.7	0.0
	Sept. 9, 1957	3.8	0.42
	Dec. 8, 1957	0.77	—
	Jan. 12, 1958	0.91	—
	Dec. 9, 1959	0.7	1.2
	Aug. 21, 1957	1.1	0.15
Livingston	Aug. 22, 1957	3.5	0.0
	Aug. 26, 1957	3.2	0.1
	Aug. 29, 1957	2.0	1.2
	Sept. 13, 1957	6.9	5.6
	Sept. 20, 1957	1.27	2.43
	Jan. 21, 1958	1.52	—
	Feb. 6, 1958	2.02	—
	July 25, 1958	0.74	1.55
	Aug. 4, 1959	1.31	0.59
	Sept. 13, 1957	2.9	1.1
	Oct. 9, 1957	0.85	—

tributaries, in the Lamar River, in the Yellowstone River as far downstream as Emigrant, and from Trout Lake in the Soda Butte Creek drainage. Each sample consisted of one gallon from the surface of the water and one gallon 1 to 2 feet below the surface. Each gallon was made up of water from both sides and from the center of the stream. Some of the surface and subsurface samples were combined in the laboratory to form a mixed 2-gallon sample. Samples were acidified with sulfuric acid in the field to avoid the development of high pH values and breakdown of the sample.

Bottom invertebrates

The several bottom types at nine stations in the tributaries and the Lamar and Yellowstone Rivers made it impossible to use one method for securing indices of abundance of aquatic invertebrates for all stations. The Surber square-foot sampler was used (10 square feet of collection) wherever the bottom material was small enough. Where this gear was not appropriate, the collections consisted of organisms taken from 20 rocks about 8 inches in diameter. Collections were made at all stations before spraying, just after spraying, and periodically throughout the season into mid-September. Follow-up counts were made in 1958.

Drift samples

A plankton net was used in Tower Creek on July 13 and 14, both before and after

spraying, to determine the numbers of aquatic invertebrates drifting downstream in the current. The net had a 9½-inch hoop and 38-mesh bolting cloth. Fishing time was 5 minutes per set.

Aquatic vegetation

Two species of *Potamogeton* were collected from a few streams and lakes before and after spraying. Each sample consisted of two handfuls of plant material which was placed in a plastic bag and frozen before analysis for DDT content.

RESULTS

Fish

No mortality attributable to DDT was found among fish noted in our limited observations. All of the 80 fish samples analyzed contained DDT, and all but four of the 57 tested for DDE contained that metabolite. Table 3 summarizes the results of the analyses on trout, and Table 4 lists the results on mountain whitefish. The data suggest certain general patterns with respect to amounts of DDT present, but it is obvious that much variation exists from fish to fish and that caution must be used in interpreting the results.

Lamar River cutthroat trout contained relatively high concentrations of DDT, with the fish collected on August 14 having 11 p.p.m. Certain tributaries of the Lamar River received relatively high dosages of spray, which may account for the high residues measured. Collections made in 1958 in the Lamar showed high residues, but the one collection in 1959 was relatively low. Slough Creek and Cache Creek also had fish with high DDT contents in 1957, but 1958 samples were relatively low. In Buck Lake, cutthroat trout had high levels in 1957 and lower ones in 1958 and 1959.

Downstream in the Yellowstone River the DDT contents of trout were somewhat lower than in the upstream tributaries. At Emigrant, 1957 collections of trout and whitefish had higher residues than did the 1958 and 1959 samples. Whitefish in the Yellowstone had approximately the same DDT levels as cutthroat, rainbow, and brown trout, one whitefish sample containing 6.9 p.p.m. of DDT. There is a suggestion in the data from Corwin Springs and Emigrant that whitefish collected in September 1957 contained more DDT than those collected earlier. It appears that trout collected near Livingston had as much DDT as those captured upstream near Corwin

TABLE 5.—DDT content of cutthroat trout from an apparently untreated area, Pelican Creek, 1958 and 1959

Date collected	DDT content (p.p.m.)	
	Chemical assay	Fly bioassay
June 15, 1958	0.48	0.42
June 15, 1958	0.28	—
June 15, 1958	0.17	0.17
June 15, 1958	0.45	—
June 15, 1958	0.49	0.33
June 15, 1958	0.21	—
June 10, 1959	0.46	—

Springs and near Emigrant. The two samples of longnose dace analyzed contained much less DDT than did cutthroat trout collected at the same time and the same place in the Lamar River. Two samples, taken on August 9, 1957, had 0.76 and 0.28 p.p.m., respectively, of DDT. Cutthroat trout from Buck Lake and rainbow trout from Trout Lake contained relatively large amounts of DDT.

Cutthroat trout from Pelican Creek, a tributary to Yellowstone Lake, were selected as control fish for analysis for DDT because no spray program was known to have been carried on within 30 miles. Fish had no opportunity to swim from a sprayed area into Pelican Creek, since impassable falls blocked their

way. Analysis of Pelican Creek cutthroat collected on June 15, 1958, revealed the presence of DDT in all six fish tested (Table 5). In order to test the validity of the chemical method that achieved positive readings in control fish, fly bioassay tests were run on three of the fish. DDT was found to be present by this test, and in about the same amounts as shown chemically (Table 5). Fish collected in Pelican Creek on June 10, 1959, were also found to contain DDT, and amounts similar to those collected in 1958. We must conclude, therefore, that the cutthroat from Pelican Creek contained DDT even though we can recognize no source of contamination.

Water

Our interest in exposed waters follows the spraying of DDT principally concerning the amount of DDT and the duration of its presence in streams and lakes. The samples analyzed do not show clear relationships between DDT content and the progress of the season in each body of water, because sampling proved to be less frequent than would have been desirable (Table 6).

The Lamar River contained 0.01 p.p.m. of DDT on the morning of July 18. Many t

TABLE 6.—DDT content of water samples collected in the Yellowstone River drainage in July 1957

[Tr. denotes less than 0.01 p.p.m.; N.D. denotes no detectable DDT]

Locality	Date	Hours since last spray	Hour	Depth	DDT content (p.p.m.)
Pebble Creek	12	3	8:30 a.m.	Surface	Tr.
Pebble Creek	12	3	8:30 a.m.	Subsurface	Tr.
Soda Butte Creek	12	3	7:30 a.m.	Surface	Tr.
Soda Butte Creek	12	3	7:30 a.m.	Subsurface	Tr.
Lamar River	15	4	9:00 a.m.	Surface	Tr.
Lamar River	15	4	9:00 a.m.	Subsurface	Tr.
Lamar River	18	4	9:15 a.m.	Combined	0.01
Lamar River	20	1	5:45 a.m.	Combined	0.03
Slough Creek	15	26	8:15 a.m.	Combined	N.D.
Tower Creek	13	1	6:00 a.m.	Surface	0.010
Tower Creek	13	1	6:00 a.m.	Subsurface	0.011
Yellowstone River near Tower Junction	11	3 ¹	8:30 a.m.	Combined	0.01
Yellowstone River at Corwin Springs	12	5 ¹	10:00 a.m.	Combined	N.D.
Yellowstone River at Corwin Springs	13	5 ¹	12:00 noon	Combined	N.D.
Yellowstone River at Corwin Springs	14	9 ¹	1:45 p.m.	Combined	N.D.
Yellowstone River at Corwin Springs	15	6 ¹	11:00 a.m.	Combined	0.01
Yellowstone River at Corwin Springs	17	6 ¹	11:00 a.m.	Combined	N.D.
Yellowstone River at Corwin Springs	18	6 ¹	11:00 a.m.	Combined	0.01
Yellowstone River at Corwin Springs	19	8 ¹	1:30 p.m.	Combined	N.D.
Yellowstone River at Corwin Springs	22	8 ¹	1:00 p.m.	Combined	N.D.
Yellowstone River at Corwin Springs	23	5 ¹	10:00 a.m.	Combined	N.D.
Yellowstone River at Emigrant	22	6 ¹	11:30 a.m.	Combined	Tr.
Trout Lake	18	3	8:15 a.m.	Combined	0.50

¹ Spraying was done several miles upstream.

TABLE 7.—Numbers of bottom invertebrates in Tower Creek, Soda Butte Creek, and the outlet of Trout Lake in 1957–58

[Numbers are the totals found in 10 combined Surber square-foot samples]

Date	Plecoptera	Ephemeroptera	Trichoptera	Diptera	Other	Total
Tower Creek ¹						
Pre-spray						
7-2-57	48	10	9	0	0	67
Post-spray						
7-30-57	5	27	2	0	0	34
8-6-57	2	5	2	0	0	9
8-19-57	7	26	6	19	3	61
8-30-57	26	16	0	63	2	107
9-12-57	23	4	4	2	6	39
7-18-58	3	72	41	0	0	116
8-29-58	52	82	32	4	2	172
Soda Butte Creek ²						
Pre-spray						
7-2-57	8	18	7	0	1	34
Post-spray						
7-26-57	0	0	0	0	0	0
8-5-57	3	0	1	0	0	4
8-19-57	1	2	1	90	0	94
8-30-57	0	0	14	15	0	29
9-12-57	0	0	20	6	0	26
7-18-58	1	5	2	11	0	19
8-29-58	2	4	4	15	0	25
Trout Lake Outlet ³						
Pre-spray						
7-2-57	750	30	185	35	10	910
Post-spray						
7-25-57	74	24	10	0	0	108
8-5-57	4	17	2	1	2	26
8-19-57	458	3	25	2	0	488
8-30-57	963	0	17	0	5	985
9-12-57	83	15	19	20	22	159
7-18-58	203	27	17	30	250 ⁴	527
8-29-58	586	94	6	35	2	723

Last spray July 14.
 Last spray July 20.
 Last spray July 18.
 Hydracarina.

ries upstream from the collecting point had been sprayed in the preceding 8 days, but it seems likely from examination of Tables 2 and 6 that the spray applied on the morning of July 18 in areas on the Lamar River, Lower Tower Creek, Soda Butte Creek, and other places in the Lamar drainage was responsible for the 0.01 p.p.m. of DDT. The reading of 0.03 p.p.m. on the morning of July 20 was probably caused by the spray of that same morning on the Lamar River, since the sample was taken at 5:45 a.m., shortly after the spray had been applied. Slough Creek contained no DDT on July 15 despite the fact that a tributary, West Slough Creek, had been sprayed the day before. The Yellowstone River near Tower Falls had 0.01 p.p.m. of DDT at 8:30 a.m. on July 11. This result can probably be traced to that morning's spray on Tower Falls and the Yellowstone River Canyon, rather than to the previous day's spraying on the Yellowstone River Canyon.

Yellowstone River water at Corwin Springs was sampled on 9 days, from July 12 to 23. No spray was deposited in drainages upstream from this point every day from July 10 to 23,

and it is likely that DDT from each spraying reached some stream and was washed into the Yellowstone River. It might be expected that DDT would be found in the Yellowstone River at Corwin Springs during the entire 14-day period, unless it was dissipated, quickly washed away, or adsorbed along the way. The data show that DDT was found in the water at this point on only 2 of the 9 days on which samples were taken, suggesting that either the DDT was usually washed downstream quickly on each occasion or that extremely large amounts of DDT entered the drainage on these two occasions. It would appear that concentrations went downstream in blocks, rather than spreading out and lingering for periods of time.

The Yellowstone River at Emigrant contained a trace of DDT on July 22. It is difficult to assign this to any particular concentration of DDT spray, since the river distances are great. There was widespread spraying on July 21, the last day of the spray period, and this may have been responsible for the presence of DDT in the sample from Emigrant.

The sample of July 18 from Trout Lake,

TABLE 8.—Numbers of bottom invertebrates in Slough Creek and the Lamar River in 1957 and 1958
[Numbers are the totals found on 20 combined rock samples]

Date	Plecoptera	Ephemeroptera	Trichoptera	Diptera	Other	Total
Slough Creek at campground						
Pre-spray						
7- 2-57	102	45	21	5	0	173
Post-spray						
7-18-57	6	0	24	0	6	36
8- 5-57	3	1	1	0	0	5
8-19-57	13	0	9	0	1	21
8-30-57	2	0	6	0	14	22
7-18-58	0	0	11	0	0	11
Slough Creek at mouth						
Pre-spray						
7- 5-57	95	132	63	0	0	290
Post-spray						
7-21-57	2	0	9	0	1	12
8- 5-57	8	0	12	0	5	25
8-19-57	1	2	3	0	1	7
8-30-57	1	1	4	0	9	15
9- 2-57	6	1	20	4	1	32
8-29-58	4	86	22	17	52	181
Lamar River						
Pre-spray						
7- 2-57	20	2	9	0	0	31
Post-spray						
7-21-57	0	0	5	0	0	5
7-26-57	0	0	0	0	0	0
8- 5-57	3	0	2	0	0	5
8-19-57	2	0	1	0	0	3
8-30-57	0	0	2	0	1	3
9-12-57	3	0	6	0	0	9
8-29-58	3	4	6	2	1	16

¹ Last spray July 21.

the only lake sample analyzed, shows that there was 0.5 p.p.m. of DDT. This concentration was by far the highest measured and suggests that the lake acted as a reservoir for the DDT and released it slowly through the outlet. Trout Lake was in the spray area on July 18 and could also have received some drifting spray on July 14, 16, and 17.

Bottom invertebrates

Measurements of numbers of bottom invertebrates were made to determine if there were reductions that could be related to the application of DDT spray (Tables 7, 8, 9). Such reductions would be of much importance to fish, since they would significantly reduce the food supply, and since dead or dying organisms containing DDT may be consumed by fish. Studies to be mentioned later have shown these factors to be important to the welfare of trout populations.

The numbers of bottom invertebrates in Tower Creek 2 weeks after spraying were about half those present 1½ weeks before spraying, with the stoneflies and caddisflies suffering the greatest reductions (Table 7). Mayflies increased in numbers. Good repopulation had taken place by the middle of 1958. In Soda Butte Creek, where moderate numbers of insects had been counted before the

spray, none could be found 1 week after spray. There was a repopulation later in season, however, especially of dipterous sects and caddisflies. After 1 year the population numbers were about the same as before the spray, but species composition was different. The number of all forms present in outlet of Trout Lake was reduced, with stoneflies, caddisflies, and Diptera showing greatest changes. There was a further reduction in numbers in this stream by August 5, followed by rapid increases to pre-spray numbers. In August 1958 insect numbers were generally high, due to an abundance of stoneflies. Caddisflies, however, were low numbers.

In Slough Creek at the campground and at the mouth, large decreases in numbers were measured shortly after spray time (Table 8). Stoneflies, caddisflies, mayflies, and dipterans showed extreme changes in numbers. Repopulation during the rest of the season was indicated but was not as extensively measured as in Tower, Soda Butte, or Trout Lake Creeks. In the summer of 1958 numbers of insects at the campground and near the mouth were still below pre-spray numbers. In the Lamar River, a relatively unproductive stream, there appeared to be a significant reduction in bottom organisms after the spray,

TABLE 9.—Numbers of bottom invertebrates in the Yellowstone River in 1957 and 1958¹

[Numbers are the totals found on 20 combined rock samples]

Date	Plecoptera	Ephemeroptera	Trichoptera	Diptera	Other	Total
At Corwin Springs						
Pre-spray						
7-3-57	160	102	17	0	0	279
Post-spray						
7-21-57	14	3	12	0	0	29
7-26-57	9	0	6	0	0	15
8-5-57	6	0	10	0	0	16
8-23-57	31	9	0	1	0	41
	(14 large) (17 small)					
9-12-57	10 small	21	35	6	0	72
7-16-58	21	2	8	5	0	36
8-29-58	35	91	103	39	15	283
At Emigrant Bridge						
Pre-spray						
7-29-57	19	0	9	0	13	41
8-5-57	10	2	3	0	2	17
8-23-57	21	22	5	2	19	91
	(9 large) (12 small)	(9 large) (13 small)				
9-12-57	10 small	26	17	6	21	70
7-16-58	7	33	6	22	3	71
8-29-58	83	62	245	56	16	462
Above Livingston						
Pre-spray						
7-29-57	17	2	11	0	0	30
8-5-57	24	0	8	0	0	32
	(18 small) (6 large)					
8-23-57	27	10	9	3	0	49
	(19 small) (8 large)					
9-12-57	25 small	60	14	4	85	188
7-16-58	17	7	35	52	0	111
8-27-58	42	45	118	95	8	308

Last spray upstream July 21.

all numbers of caddisflies being the only ones found until August 5. Repopulation did not reach pre-spray levels by September 12, 1957, although a little comeback was measured. A year later further recovery had been made.

A pre- and post-spray comparison of Corwin Springs, Yellowstone River, was made (Table 9). The change from July 3 to July 21 was great, with large reductions of stoneflies and caddisflies. Further reductions were indicated a week later, and a slow repopulation after that was suggested. Numbers in August 1958 were at pre-spray levels, but the species composition was altered. Post-spray samples at Emigrant and Livingston contained bottom organisms in the same order of magnitude as those at Corwin Springs and showed repopulation in about the same pattern. Repopulation at Emigrant and Livingston was indicated by the appearance in August of many early-instar mayfly and mayfly nymphs, which increased the total numbers over those in earlier samples. The appearance at Emigrant and Livingston of many immature gastropods in August and September accounts for increases in total numbers.

Drift samples

Drift-sample measurements were taken in Tower Creek to obtain an index of dead and dying aquatic invertebrates in the stream following DDT spraying (Table 10). A pre-spray sample taken at 4:00 a.m. on July 13 contained 85 organisms. The first post-spray sample, taken at 6:00 a.m., showed an increase in numbers of drifting invertebrates, and one taken at 8:00 a.m. showed a further increase. On July 14 a larger spray application was made in the same drainage, and by 7:30 a.m. the sample contained more than seven times the numbers of invertebrates found in the pre-spray sample.

Aquatic vegetation

The three samples of *Potamogeton* which were analyzed for DDT (Table 11) all contained greater concentrations than the water samples from the same localities.

DISCUSSION

The questions as to whether DDT spray moves downstream in a block, and whether DDT may linger for hours in one place in a

TABLE 10.—Numbers of aquatic invertebrates collected in 5-minute plankton-net samples in Tower Creek

Date and hour	Hours after spray	Plecoptera	Ephemeroptera	Trichoptera	Diptera	Other	Total
First spray							
July 13							
4:00 a.m.	Pre-spray	58	14	10	3	0	85
6:00 a.m.	1	90	10	5	4	0	109
8:00 a.m.	3	85	19	54	49	0	207
Second spray							
July 14							
5:30 a.m.	½	81	19	1	2	1	104
7:30 a.m.	2½	432	91	84	6	0	613

moving stream are partially answered by this study. It is probable that if the toxicant stayed in the waters of streams for many hours, we would have collected positive samples at Corwin Springs on the Yellowstone River on more than two of the nine occasions. For 11 consecutive days DDT was sprayed in this drainage. The spray that reached streams was funneled into the main stem and flowed past Corwin Springs. It appears that the DDT was either so diluted when it reached this point that it could not usually be measured, or it passed downstream in well-defined slugs that were not sampled in our program. The report by Cope and Park (1957) shows that Canyon Creek, a stream with a discharge of 50 c.f.s. on the Beaverhead National Forest in Montana, had 0.10 p.p.m. of DDT in the water while the spray was being applied, 0.33 p.p.m. a half hour after the end of spray time, and 0.00 p.p.m. 27 hours later. Canyon Creek is similar in size and gradient to many of the tributaries in the Yellowstone River system which were sprayed in 1957, and the data from both studies suggest that the DDT moved downstream in a matter of hours.

Graham and Scott (1959) found on the Ruby River, a meandering stream in Montana, that traces of DDT were in the surface water 32 hours after spraying in a situation in which 0.01–0.02 pound per acre reached the ground at the river's edge.

The dissipation of DDT as it moves downstream is important in the interpretation of data on DDT content of fish in downstream areas. DDT was present in fish below Livingston, which lies about 85 stream miles below the lowermost spray area, and at Emigrant, about 55 stream miles below the lowermost spray area. It has been generally assumed, and reported by Savage (1949), that the effect of DDT rapidly diminishes as it is carried downstream from the spray area. Kerswill and Elson (1955) reported many dead suck-

ers of various sizes having been collected a counting fence 10 miles below an area sprayed with DDT in the Miramichi River drainage in New Brunswick. Graham and Scott (1959) found 0.01 p.p.m. of DDT in the Ruby River 4 miles below the spray area, 48 hours after the spray was applied.

No unusual numbers of dead fish were found during the present study, and it is concluded that the DDT was not present in the waters in quantities great enough to cause extensive acute mortality of fish.

Relating the DDT spray to the significant reductions in numbers of fish-food organisms in Tower, Soda Butte, and Slough Creeks, the Lamar and Yellowstone Rivers may be difficult in view of the possibility of emergence as adults of some of the aquatic insect populations. A 2- to 3-weeks' time lapse in emergence cases between pre-spray and post-spray samples was sufficient for some insect populations to emerge in large enough numbers to cause significant reductions of immature forms. Drift samples from Tower Creek, however, appeared to show that reductions in bottom fauna in that stream were caused by the DDT spray and not by emergence. The numbers of dying and dead aquatic insects collected in plankton nets before and after the spray showed la-

TABLE 11.—DDT content of vegetation samples (Potamogeton sp.) collected from affected waters in 1957

Locality	Days after last exposure	Date collected	DDT content (p.p.m.)	High DDT content found in water (p.p.m.)
Lamar River	15	August 5	1.7	0.0
Slough Creek, at campground	15	August 5	2.3	N.
Yellowstone River, at Corwin Springs	16	August 6	0.8	0.0

¹ No detectable DDT.

creases within a few hours after spray time and coincided with the reductions measured at the stream bottom. This follows the pattern reported by Cope and Park for Trapper and Canyon Creeks (1957) and by Graham and Abbott (1959) in the Ruby River. Here, large numbers of aquatic invertebrates were collected in plankton nets a few hours after spraying. One and 2 days later the drifting organisms were collected in pre-spray numbers and a few weeks later the counts of bottom organisms showed significant losses. Hoffman and Abbott (1948) collected drifting insects in Park Creek, West Virginia, after a treatment with wettable DDT. The largest numbers of insects drifting downstream occurred within the first 3 hours after spraying. At the end of 48 hours the number of drifting insects was reduced almost to pre-spray levels.

The interpretation of these bottom-sample numbers in relation to effects of DDT in Yellowstone streams must be carefully studied before cause and effect can be established. The efficiency of sampling was such that only gross changes can be considered. The grouping of organisms into orders, rather than into lower categories, also requires that small differences in total numbers must be disregarded, and the changes in species composition are overlooked. Moreover, insects with short life cycles can pupate and emerge between samplings, giving the effect of changes which might be ascribed to DDT. In other instances, delay between samplings can account for significant increases in population size. For example, in the Trout Lake outlet sample of August 5 there was a large decrease in numbers of bottom organisms, probably caused by DDT toxicity (Table 7). This low was followed by a substantial buildup. The increase noted on August 19 consisted of large numbers of early-instar stonefly nymphs which probably came from eggs laid after the spray was deposited. A similar condition was also noted in Tower Creek on August 30 when large numbers of small stonefly nymphs and dipteran larvae appeared, apparently from post-spray egg-laying.

The pattern of bottom-fauna incidence measured on Tower and Soda Butte Creeks, Trout Lake outlet, and the Yellowstone River at Emigrant was characterized by a buildup of organisms followed by a reduction in September. In the Yellowstone River the reduction may have been caused by the emergence of stoneflies since the last August collection showed large and small nymphs, while the

September 12 collection had only small ones. In Tower Creek the buildup was caused by stoneflies and dipterans. The last collection had few dipterans, so a fly emergence was probably responsible for the September reduction. The flies in Soda Butte Creek also may have emerged in late August to cause a loss of bottom fauna. The changes in bottom fauna in the various streams all show significant reduction in insect numbers soon after application of the DDT.

It is difficult to relate amounts of DDT in aquatic vegetation in late season to amounts in the water or in the fish, because the vegetation grows after the DDT is adsorbed and aquatic invertebrates graze on the vegetation. It is probable, however, that the DDT contained in aquatic plants enters the bodies of fish, directly or indirectly, and that enough may be ingested to affect the welfare of the fish or be stored in their tissues.

Relatively high levels of DDT were found in the bodies of whitefish and trout during this study compared with the amounts found in the water. Assuming that the fish did not move great distances from the beginning of the season to the end, the manner in which fish acquired DDT in amounts so much greater than any measured in the water or in the limited amount of aquatic vegetation tested is of considerable interest. For example, in the Yellowstone River at Corwin Springs, the largest amount of DDT found was 0.01 p.p.m. in water and 0.08 p.p.m. in aquatic vegetation, while up to 3.8 p.p.m. of DDT was found in whitefish. At Emigrant only a trace of DDT was found in the water, yet 6.9 p.p.m. was found in a whitefish. In Trout Lake 0.50 p.p.m. of DDT was in the water sample analyzed, but rainbow trout contained 4.9 p.p.m. of DDT and 0.7 p.p.m. of DDE 8 days later.

Graham and Scott found from 1.30 to 5.80 p.p.m. of DDT in rainbow and brown trout taken alive from the Ruby River in Montana. These fish were collected about 9 weeks after airplane spraying in the study area. Amounts of DDT in samples of water from the river ranged from 1.35 p.p.m. 5 minutes after the spraying to 0.00 p.p.m. 48 hours after the spraying, with most samples containing less than 0.05 p.p.m. These residues compare favorably with amounts found in the Yellowstone River drainage fish from upstream areas at about the same time after the spraying.

Hunt and Bischoff (1960) reported on a DDD gnat-control project in Clear Lake,

California. Treatment was begun in 1949, when 1 part of DDD in 70 million parts of water was dispersed in the lake. Treatments were also made in 1951 and 1954, at the rate of 1:50 million. In 1958 specimens of several species of live fish were collected and their visceral fat analyzed for DDD content. DDD in the fat amounted to 40 p.p.m. in carp and 2,500 p.p.m. in brown bullhead, with other species having intermediate amounts. Later collections in 1958 again showed extremely high DDD levels in the visceral fat and in the fat of edible flesh, especially in black crappie, largemouth bass, and brown bullhead. Visceral fat from white catfish had up to 2,375 p.p.m. of DDD, from largemouth bass, up to 1,700 p.p.m., from black crappie, up to 1,600 p.p.m., and from brown bullhead, up to 2,500 p.p.m. Edible flesh contained DDD up to 221 p.p.m. in white catfish, up to 138 p.p.m. in largemouth bass, up to 115 in black crappie, and up to 79.9 p.p.m. in brown bullhead. Evidently the long exposure at low levels resulted in high levels of DDD in the fish without producing mortality.

DDD enters the fish body from water and in food. Cottam and Higgins (1946) reported on experiments with warm- and cold-water fishes which demonstrated that the most toxic effects were produced when DDT was fed on or incorporated in food, and that DDT was definitely more toxic when dissolved in oil than when given in fat-free carbohydrates or proteins. In view of the experience cited above it is probable that the DDT found in fish in the Yellowstone drainage entered through the ingestion of dead and dying insects. The water contained large numbers of drifting insects affected by the DDT-oil spray. It is not known how much DDT was present in or on the insects, or whether the fish ate them in abundance, but experience indicates that the fish would eat drifting insects. On Canyon and Trapper Creeks in 1956, it was observed that some trout in live-cars ate large amounts of the affected insects and that trout free in the streams gorged themselves on this diet. This engorgement has also been observed elsewhere.

The DDT contents of these fish indicate that an accumulation of DDT took place in the tissues as has been shown by numerous authors reporting on warm-blooded vertebrates. The rate of consumption of DDT by fish in the Yellowstone River is not known, but apparently there was considerable buildup of DDT.

The greater amount of DDT in fish in 1957

than in 1958 and 1959 might be expected. Weighed against the accumulation of residues through ingestion of DDT-bearing animal and plant material are the processes of metabolism and excretion of the toxicant, growth of fish, and possible mortality of fish with excessive amounts in storage. The data suggest the possibility of an increase in the amount of DDT stored for a few months, followed by a slow process of loss of DDT over a period of many months.

The presence of DDT in fish from an apparently untreated area of Pelican Creek raises questions regarding the interpretation of positive determinations in fish from treated areas. The DDT levels in the fish from Pelican Creek were somewhat less than 0.5 p.p.m. and 13 of the 80 positive samples from treated areas had less than this amount. This may suggest that many fish commonly have low levels of DDT in their bodies and that the spruce-budworm spray program may not have been the cause of all of the residues found in fish from the Yellowstone River drainage. In the absence of analyses of water from Pelican Creek, and without zero controls from the tissue, it appears impossible to resolve questions concerning these residues. It was during a search for uncontaminated fish for control purposes that the Pelican Creek fish were analyzed and found positive, and other fish analyzed for this purpose were also found positive.

The presence of DDT and other chlorinated hydrocarbons may not be as unusual as is commonly thought. The Fish-Pesticide Research Laboratory at Denver has frequently found toxicants in control trout and other fish and it has not always been possible to trace the origins of these materials.

The reliability of the Schechter-Haller method is not questioned, despite the difficulties in consistent extraction and in making valid determinations at low levels. Interfering substances were removed before analysis, so contamination cannot be suspected. The verification of chemical measurements on Pelican Creek fish by fly bioassay lends credence to the reliability of the chemical analyses.

Consideration must be given to the possibility that part of the DDT residues found in fish and after 1957 may in fact have originated during the 1955 spraying. The 2-year retention of DDT residues from the 1957 treatment forces us to recognize that a long-term storage of DDT in fish tissues could have begun

1955 and extended beyond the time of the samplings in 1957.

The comparison of precise amounts of DDT residue with those in other fish from other times at other times is difficult because of the conversion of DDT to DDE and DDA in an animal body. Since this process proceeds at different rates in different individual fish, it appears dangerous to compare residues in the Pelican Creek trout with those of the Yellowstone River trout without knowing when the exposure took place in the Pelican Creek area.

The Montana Fish and Game Department reported numbers of catchable-sized rainbow trout and cutthroat trout in the affected area of the Yellowstone River in 1957. The question arises as to whether these fish contained amounts of DDT different from those of wild fish in the same waters has not been determined. Fish of hatchery origin, recognized through scale growth patterns, contained DDT in amounts similar to those in wild fish. Examination of stocking records indicates that the stocking took place before the end of the spray period.

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Survival of Brook Trout from Egg to Fingerling Stage in Two Michigan Trout Streams

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ABSTRACT

Survival of wild brook trout (*Salvelinus fontinalis*) from the egg to the end of the first summer of life was investigated at the Hunt Creek Trout Research Station, Montmorency County, Michigan, during 1943-48, by confinement of spawners of known size and number in screened diversions, followed by direct enumeration of the resulting fingerlings. The numbers of eggs deposited were estimated from size of spawners. Percentage survival observed in six diversion experiments ranged from 4.5 to 31.7. Survival from egg to fingerling was estimated also for unconfined, natural populations in the Pigeon River and in Hunt Creek (the natural channel) during 1949-58. Consecutive fall population estimates gave the number of breeders present one fall and the number of fingerlings surviving to the following fall. Egg production for the population of breeders was estimated from egg-count data. From a series of 12 population estimates, survival rates from egg deposition to the following September ranged from 2.7 to 6.7 percent (significantly lower than in the diversion experiments at Hunt Creek). For a total of 24 observations (from confinements in diversions at Hunt Creek and Convict Creek, plus population studies on the Pigeon River and Hunt Creek), the percentage survival from egg to fall fingerling ranged from 2.7 to 43, and averaged 8.6. Excluding what appear to be unduly high results from four of the observations, the survival rates ranged from 2.7 to 8.8 percent (average, 4.7).

INTRODUCTION

The purpose of this study was to determine the percentage survival of brook trout (*Salvelinus fontinalis*) from the egg stage (approximately in mid-winter) to the fingerling stage of the following early fall. Two investigational methods were utilized. (1) Wild mature male and female brook trout of known sizes were confined in screened diversions of Hunt Creek and allowed to spawn. The young-of-the-year survivors were collected and enumerated during the following late summer or fall and their numbers compared to the estimated numbers of eggs deposited. Similar procedures were used by Smith (1947) in a study at Convict Creek, California. (2) In the second method, successive fall population estimates, by mark-and-recapture with an electric shocker, gave the numbers of mature fish present during a fall spawning season and the numbers of fingerlings which survived to the following fall. Potential egg production by the spawners was computed from the records of number and size of adult females present and from counts of ovarian eggs per female related to size.

EXPERIMENTS IN SCREENED DIVERSIONS OF HUNT CREEK

The screened diversions (II and III), where controlled spawning experiments were conducted, lie in the mid-portion of Section C of Hunt Creek (Figure 1) which, on the basis of the numbers of young and adults observed

annually, is considered good brook trout habitat. These diversions, constructed in 1914, are equipped with concrete bulkheads which accommodate stop-logs and vertical screen. Diversion II is 193 feet long, 9 to 14 feet wide, and has an area of 0.05 acre; diversion III is 284 feet long, 8 to 14 feet wide, and has an area of 0.07 acre.

The ecological characteristics of the natural channel of Hunt Creek were described by Shetter and Leonard (1943). In 1943, when the present study was begun, diversions II and III were well established, natural in appearance, and apparently similar in physical characteristics to the natural channel. Both diversions have adequate bottom material (gravel) for brook trout spawning. Surface flows only at the edges or immediately upstream from the bulkheads during colder portions of the winter. There are some habitat differences between diversions. Rock areas predominate in diversion III and gravel areas in diversion II. Spring water seepage occurs along approximately one-third of the west bank of diversion III, and a somewhat smaller amount of ground water flows into diversion II.

In addition to brook trout, the slimy sculpin (*Cottus cognatus*) was quite abundant in both diversions; the bluntnose minnow (*Phoxinotus notatus*), fathead minnow (*Pimephales notatus*), and northern redbelly dace (*Chrosomus commersoni*) were relatively rare.

The number of female brook trout spawners placed in the diversions amounted to

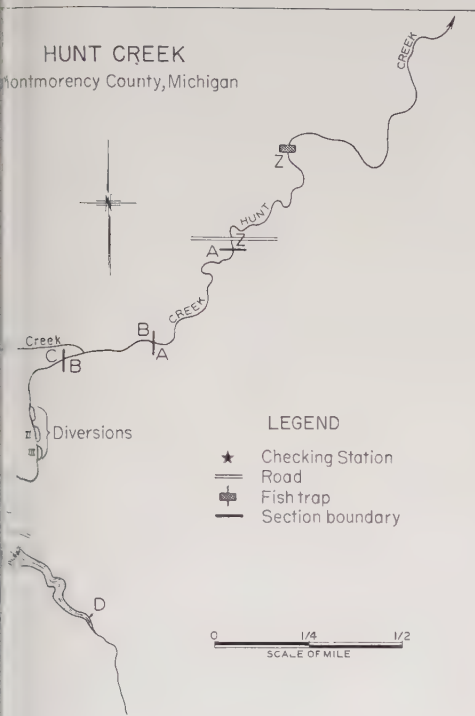


FIGURE 1.—The Hunt Creek Trout Research Area, Montmorency County, Michigan, showing the diversions and stream sections of particular interest in the study.

435 square feet or more of stream. The results therefore would apply to a situation with a low density of eggs per square foot of stream, where few other fish are present.

Collection of experimental fish and handling procedure

In the northern Lower Peninsula of Michigan brook trout rarely spawn before mid-October, and often the peak of activity is not before the first week of November. In the present experiments adult females were put into the diversions several days before they were ready to spawn. Experimental fish were collected between September 23 and October 19 in all years except 1943 when they were collected on October 29. In autumn the sexes were easily identified on the basis of secondary sexual characters. The spawners were collected with seines in 1943, but in 1944 and subsequent years brood fish were taken with alternating-current shocker (110/220 volts, 10 amperes) as described by Shetter (1947). The year before the experimental fish were released in the diversions, they were measured and

weighed, and except in 1943 were jaw-tagged. The average total lengths and weights of males and females in the diversions, the mean loss in weight resulting from spawning, the estimated number (with 95-percent confidence limits) of eggs deposited by the females, and the observed number of unspawned eggs retained by the females after spawning are shown in Table 1.

After the spawning season in 1943, removal of the spawners by gill-netting, trap-netting, and dip-netting was attempted, but 5 of the 15 trout used were not recovered. In 1944–47 all spent females and most males were removed by electro-fishing within the period December 1–12. By this time the eggs were in the eyed stage and were quite resistant to injury which might result from the shocker operations. The females were dissected to determine the numbers of mature eggs which were retained, but surviving males were liberated outside the experimental diversions.

Estimation of numbers of eggs deposited

The estimated number of eggs deposited was determined from two regression equations developed from egg counts made on 56 female brook trout collected in the Hunt Creek drainage, mostly in 1939 and 1943.¹ Fifty-two fish were taken during August, three in July, and one in October. All except the latter (trap-netted) specimen were obtained by angling.

Vladykov (1956) demonstrated that egg counts made on brook trout females collected as early as August are likely to be misleading and yield counts appreciably higher than the probable numbers deposited in the redds during October or early November. He showed that as the maturing ovarian eggs increased in diameter from 1 to 4 millimeters, the number was reduced about 36 percent as the result of atresia. The average diameters of 40 maturing eggs from each of 13 females collected from the Hunt Creek drainage in August 1943 ranged from 1.2 to 2.5 millimeters. On the basis of these diameters and data presented by Vladykov (1956), I estimated that the August counts of eggs in brook trout were 20 percent higher than the number which these fish would have laid during the following spawning season. In calculating the regression line for egg production of trout in

¹ Individual measurements and egg counts on these fish are on file at the Hunt Creek Trout Research Station.

TABLE 1.—*Source, number, size, and estimated egg deposition of brook trout introduced into Hunt Creek diversions—1943–47 spawning experiments*

[Number and size of fingerlings and predatory trout collected at end of each experiment]

Item	Spawning season					
	1943	1944	1945	1946	1946	1947
Diversion	II	III	III	III	II	I
Females—source ¹	L	5S, 2L	S	L	L	L
Date spawners introduced	Nov. 2	Oct. 23	Oct. 3	Sept. 5	Sept. 26	Sept. 2
Date spawners removed	2/11/44	Dec. 7	Dec. 7	Dec. 2	Dec. 2	Dec. 2
Females						
Number introduced	5	7	5	5	1	1
Mean length (inches)	10.2	8.5	7.6	9.8	14.0	10.0
Mean weight (pounds)	0.37	0.26	0.17	0.35	1.13	0.8
Loss in weight (pounds)	0.05	0.05	0.05	0.09	0.22	0.0
Estimated eggs laid	3,832	3,732	1,660	3,304	1,777	1,388
95% confidence limits	2,657–5,007	2,706–4,774	1,104–2,218	2,051–4,461	973–2,581	1,188–1,800
Number of eggs retained	67	1	0	1	5	0
Males						
Number introduced	10	10	8	9	2	2
Number recovered	5	10	5	8	2	2
Mean length (inches) ²	8.7	8.5	7.4	9.4	12.5	10.0
Mean weight (pounds)	0.24	0.22	0.15	0.32	0.83	0.8
Loss in weight (pounds)	0.02	0.03	0.02	0.05	0.14	0.0
Fingerlings						
Date collected ³	July 8	Aug. 26–27	Sept. 11	Sept. 15	Sept. 16	Sept. 2
Number collected	173	208	527	224	156	156
Weight (pounds)	0.8	2.1	5.4	2.4	1.7	1.7
Number per female spawner	35	30	105	45	156	156
Mean length (inches)	2.4 ⁴	3.2	3.1 ⁵	3.1	3.1	3.1
Range in length (inches)	1.6–3.1	2.2–4.2	2.3–4.1	2.1–4.3	1.7–4.4	2.1–3.1
Survival (% of estimated number of eggs laid)	4.5	5.6	31.7	6.8	8.8	8.8
95% confidence limits	3.5–6.5	4.4–7.7	23.8–47.7	5.0–10.9	6.8–16.0	5.6–16.0
Predatory trout						
Number found	2	5	2	4	0	0
Range in length (inches)	6.8–9.3	4.4–5.7	5.0–6.2	6.1–8.9	—	6.2–8.9

¹ L = East Fish Lake; S = Hunt Creek.

² Average lengths of the adult fish present after spawning.

³ During calendar year following that of the spawning season.

⁴ Based on 146 measurements.

⁵ Based on 521 measurements.

the stream and pond habitats, therefore, individual counts were multiplied by a factor of 0.80. Estimations of egg numbers were based on total length of the fish.

Of female brook trout used for egg counts, most of the larger fish were taken from lake-pond habitats, and the smaller fish (less than 9.3 inches long) were collected from stream habitats. The lake-pond fish were generally deeper bodied, and their growth pattern, particularly in East Fish Lake, was such that relatively few females matured at lengths less than 8 inches. For this reason separate regression lines were prepared for stream and for lake fish (Figure 2). The regression line of number of eggs and length for stream fish (20 brook trout, 6.3–9.2 inches in length) was

$$Y = -245.91 + 76.02 X$$

where *Y* is the estimated number of eggs laid, and *X* is the length of the fish in inches. The regression line of eggs and length for pond-lake fish (36 brook trout, 7.6–16.4 inches in length) was

$$Y = -1,925.32 + 264.43X.$$

The 95-percent confidence limits were calculated by the method described by Snedecor (1957). Experimental fish from East Fish Lake were referred to the pond-lake regression line, and stream fish to the stream-regression line, for an estimate of the number of eggs produced. The estimates of production and their variances for individual female spawners were added to give the number (and its 95-percent confidence limit) of eggs deposited in each experiment.

Collection of the surviving fingerlings

Usually 6-mesh-to-the-inch vertical screens were used to confine the brood fish in their respective diversions. Following the removal of the spent fish in December, 10-mesh-to-the-inch vertical screens were substituted for coarser ones. Tests indicated that it was possible for newly hatched brook trout to pass through No. 10 mesh. The stop-log screens were packed with oakum to fill the cracks,

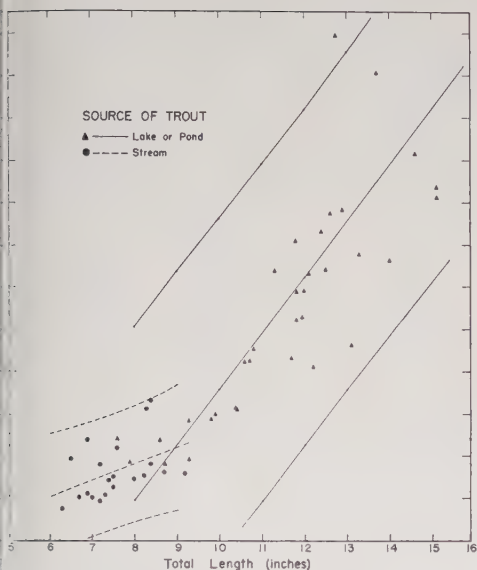


FIGURE 2.—Regression of numbers of eggs on total length for 20 stream brook trout and 36 lake and pond brook trout from the Hunt Creek drainage, 95-percent confidence limits. See text for regression formulas. (Two females from the pond-lake [14.9 inches, 3,444 eggs; 16.4 inches, 2,495 eggs] are not shown on the graph.)

ens were inspected daily and brushed to remove off water-borne debris, and flood water was bypassed around the diversions whenever water level rose. Water did not flow over the top of the blocking screens at any time during the study.

The fingerling survivors (Table 1) were collected on July 8 in 1943 and on August 27, 1944. It was observed during these years that fingerlings less than 2 inches long were difficult to capture, so subsequent collections (1945–47) were made in September. They were collected by repeated runs with the shocker, until no fish were captured on several successive runs. The water flow was blocked from the diversion, and the remaining spring water pools were treated with a dilute solution of a chlorinated bleach to capture any remaining survivors. The fish were counted, weighed, measured, and removed from the diversion.

Results in the diversions

The percentage survival, based on estimated numbers of eggs deposited and numbers of fingerlings recovered during the following summer or fall (Table 1), varied between 4.5 (1943) and 31.7 (1945). Except for 1945,

all percentages were 8.8 or less. The below-average recovery of survivors from the spawning in 1943 may have resulted in part from the late date at which the experiment was started. Some or all of the females may have deposited a portion of their eggs before confinement in the diversion.

Hobbs (1940) pointed out that superimposition of redds of brown trout resulted in loss of eggs deposited by early spawners in New Zealand streams. It is not believed that this type of loss was a factor in the Hunt Creek experiments, since the density of females never exceeded one per 435 square feet of stream, and an adequate amount of spawning gravel was available.

In five of the six diversion experiments there were two to five extraneous brook trout (4.4 to 9.6 inches long) present with the fry (Table 1). These fish may have consumed some of the fry or fingerlings, although studies at Hunt Creek (by J. W. Leonard² and by G. R. Alexander³) fail to show that such predation occurs commonly. In the six diversion experiments there was no correlation between numbers of extraneous trout present (0 to 5) and percentage survival of the fry (4.5 to 31.7). Smith's (1947) data point to a similar conclusion, even though 18 to 264 potential competitor-predator brown or rainbow trout were present in the experimental sections at Convict Creek. Retention of eggs by female brook trout was not an important factor in this study. Of 27 females used in all the experiments only 6 retained eggs and the numbers were small (Table 1).

The estimates of fingerling survival obtained under controlled conditions at Hunt Creek and Convict Creek are plotted in Figure 3 together with their respective 95-percent confidence limits. Confidence limits for Smith's (1947) estimates were obtained in a manner similar to that used for the Hunt Creek data, using his information on standard error and numbers of experimental female brook trout in the various inch-groups.

The data obtained from the diversion experiments at Hunt Creek and Convict Creek were subjected to the White rank test (Edwards, 1954), both with and without the three highest observed survival values. In neither test was there a statistically significant difference between the rates of survival at Hunt Creek and at Convict Creek.

² Institute for Fisheries Research Report No. 659 (1941), unpublished.

³ Personal communication.

SURVIVAL RATES AS DETERMINED FROM
POPULATION STUDIES

The experimental sites, where estimates of brook trout survival from egg to the first fall were calculated from population study records and fecundity data, were the Pigeon River experimental sections described by Cooper (1952), and the experimental stream sections (not the diversions) of the Hunt Creek Trout Research Station. Records from the Pigeon River are for 4.8 miles (24.10 acres) of stream in 1950, and 2.5 miles (13.06 acres) of stream in 1951 and 1952.

At Hunt Creek the population studies were conducted annually through 1.75 miles (3.91 acres) of stream. The four sections (Figure 1) are: section Z, with semi-open meadow bordered by scattered tamarack and low brush, and with varied current; section A, in old beaver meadow with low tag alders bordering the stream, and with sluggish current; section B, bordered by a dense swamp of cedar, spruce, balsam, and tamarack, and with rapid current; and section C, of which the lower one-third flows through the same swamp as section B, and the upper two-thirds is located in a narrow steep-sided valley with much shade from a mixed stand of tag alder, poplar, tamarack, and pine. Barrier weirs and fish traps are located at the lower end of section Z and at the upper end of section C. It is estimated that about 20 percent of the bottom area of the Hunt Creek experimental stream sections is suitable for brook trout spawning. A similar estimate is not available for the Pigeon River, but spawning grounds are extensive.

Species of fish most commonly encountered in the Pigeon River are brook trout, brown trout (*Salmo trutta*), rainbow trout (*S. gairdneri*), white sucker (*Catostomus commersoni*), common shiner (*Notropis cornutus*), creek chub (*Semotilus atromaculatus*), blacknose dace (*Rhinichthys atratulus*), longnose dace (*R. cataractae*), central mudminnow (*Umbra limi*), and mottled sculpin (*Cottus bairdi*). Minnows are relatively scarce in the experimental waters of Hunt Creek, as compared to numbers in the Pigeon River. In the fall population studies at Hunt Creek, white suckers, creek chubs, bluntnose and fathead minnows, and northern redbelly dace are seen only infrequently, while slimy sculpins, mottled sculpins, and mudminnows are somewhat more numerous.

Subsequent to the termination of the Hunt

TABLE 2.—Estimates of the numbers of mature female brook trout (larger than 5.0 inches), egg production, and numbers of fingerlings surviving to the following fall, Hunt Creek and Pigeon River, Michigan

Spawning season (fall)	Female spawners present	Estimated egg production	Fingerlings present, following fall	Percent survival
Hunt Creek				
1949	810	141,424	3,850	2.7
1950	802	137,840	4,189	3.0
1951	813	134,092	4,950	3.7
1952	739	124,124	5,290	4.3
1953	586	92,420	6,212	6.7
1954	810	125,356	4,164	3.4
1955	1,074	181,296	4,915	2.6
1956	882	175,208	6,654	3.8
1957	794	146,512	5,030	3.4
Pigeon River ¹				
1950	529	150,720	5,491	3.6
1951	216	62,227	2,790	4.4
1952	236	75,251	3,250	4.3

¹ From Cooper, 1953.

Creek diversion experiments described by Cooper and those reported by Smith (1947) for Convict Creek, California, considerable advancement has been made in electro-fishing equipment and techniques and their application to trout-stream population studies. When population data are combined with potential egg deposition, it is possible to estimate survival from the egg to the fingerling stage. Cooper (1953) reported such results for the Pigeon River, Michigan, for both brook and brown trout. His three estimates of brook trout survival in the Pigeon River have been combined with nine similar estimates based on Hunt Creek populations and brook trout fecundity. The population estimates reported here were accumulated during the period 1949–58, using the mark-and-recapture method in conjunction with alternating-current direct-current electro-fishing gear (Shetter 1947). The age composition of the brook trout population each fall was determined with the method described by Ketchen (1931).

Estimates of numbers of spawners present, egg deposition, and survival to the fall stage for brook trout in the open waters of the Pigeon River and Hunt Creek are given in Table 2. Only brook trout longer than 5.0 inches were considered as spawners, because egg contribution by smaller females is presumed to be negligible in the two streams.

Cooper (1953) reported on the sex maturity of 1,712 brook trout collected from different Michigan localities. Fifty-five percent of those over 1 year old were females and the percentages of mature females in different length groups were: 5.0–5.9 inches

5 percent; 6.0–6.9, 88.9; 7.0–7.9, 96.6; 8.0–8.9, 96.6; and 9.0 inches or over, 100 percent. These percentages were applied to the Hunt Creek population estimates to determine the numbers of mature females in each inch-group. The midpoint of each inch-group was arbitrarily used to compute (from Figure 2) the average and total egg production for females in this length class. The sum of the calculations for various inch-groups gave an estimate of the total egg deposition in the experimental waters of Hunt Creek each year.

The ratio of fall fingerlings to eggs deposited the previous fall gave an estimate of survival. These estimates ranged from 2.7 to 43 percent for the 9 years of the study. Cooper's three estimates on egg-to-fall survival of brook trout in the Pigeon River in 1950, 1951, and 1952 were 3.6, 4.5, and 4.3 percent, respectively. His estimates were for stream areas which were under the same fishery regulations as those in force at Hunt Creek (a creel limit of 10 fish, and a minimum length of 7 inches).

The estimated numbers of spawning female brook trout varied from 17 to 22 per acre of stream in the Pigeon River and from 189 to 214 per acre in Hunt Creek. The number of fingerlings per acre surviving to the following fall varied from 214 to 248 in the Pigeon River and from 985 to 1,702 in Hunt Creek.

These estimates can be compared with those from the Hunt Creek and Convict Creek diversion tests, which were: Hunt Creek, 20 to 43 spawning females and 1,486 to 7,529 surviving fingerlings per acre; Convict Creek, 38 spawning females and 838 to 32,550 fingerlings per acre.

The percentage survival of brook trout estimated on population estimates was mostly lower than that for the diversion tests (Figure 3). No attempt was made at either Pigeon River or Hunt Creek to compensate for movement of fingerling trout out of, or into, the population study areas.

In the light of the survival percentages estimated on population study data for natural streams in 1949–57, the three extremely high survival rates noted among the diversion tests can be unrepresentative. For example, if only 32 percent of the eggs deposited had survived to the end of the first summer in streams (as occurred in the 1945 diversion test at Hunt Creek), the fall fingerling estimates would have been on the order of 30,000 to 60,000 fish (several times

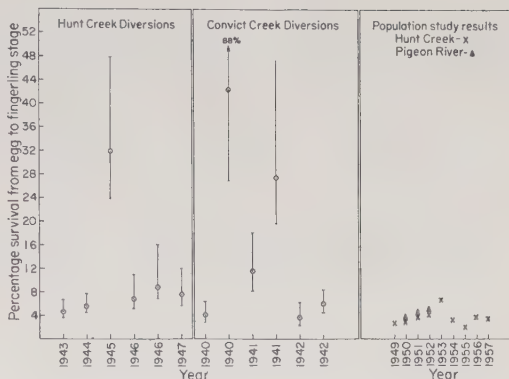


FIGURE 3.—Percentage survival of brook trout from egg to fingerling stage, determined by diversion studies at Hunt Creek and Convict Creek (with 95-percent confidence limits) and by population studies at Hunt Creek and Pigeon River.

higher than the highest of the observed estimates).

In other experiments at Hunt Creek, it has been observed that year-to-year survival of brook trout is noticeably higher in the screened diversions than in the natural channel. Possible causes of this higher survival are the low level of fish population in the diversions, and the small number of bird and mammal predators, which results from human activities at the diversions.

The 24 survival estimates (from diversions at Hunt and Convict Creeks, and from population estimates at Pigeon River and Hunt Creek) ranged from 2.7 to 43 percent (average, 8.6). Twenty of the 24 values ranged from 2.7 to 8.8 percent (average, 4.7). On the basis of these studies, a survival above 10 percent would be regarded as unusually high.

Records in the literature indicate that mortality among trout eggs in redds is relatively low as compared to mortality from egg to fall fingerling, which in the present study was found to be about 92 to 95 percent. Hobbs (1940) reported egg losses in New Zealand brown trout redds ranging from 3 to 29 percent (mostly less than 10 percent). Hazzard (1932) reported mortalities of brook trout eggs to vary from 1.5 to 73 percent (average, 20.2). Brasch⁴ investigated seven Wisconsin brook trout redds and reported an average

⁴ Brasch, John. (1949) Notes on natural reproduction of the eastern brook trout (*S. fontinalis*) with a preliminary report on several experiments on the subject. Invest. Rept. 653, Sect. Fish. Biol., Wisconsin Cons. Dept., Div. Fish Management, 9 pp. (Mimeo.)

mortality of 6.5 percent. These studies were limited to mortality of eggs while they were still in the redds.

In another series of observations Brasch⁵ placed fine-meshed screen cylinders over 16 brook trout redds in Wisconsin spring ponds. Five of the redds were not disturbed until all fry had emerged. He collected the fry as they emerged, and at the conclusion of the emergence dug up the redds. His counts of dead eggs may have been low because of egg decomposition. Brasch estimated a total mortality of 21.3 percent from the time of egg deposition to emergence as free-swimming fry. His observations agree well with those of Hobbs for brown trout in that there appears to be little mortality in the redds once the sac-fry stage is reached.

From the low rate of mortality among trout eggs in redds, as reported in the literature, it is concluded that much of the egg-to-fingerling mortality occurs after the fry emerge from the redds. In Michigan most brook trout fry emerge from redds during March; therefore most of the egg-to-fingerling mortality (reported here) must occur between March and September.

When Brasch's findings are combined with the present calculations of numbers of brook trout surviving to the end of the first summer, the following general survival patterns (with 4.7 and 8.6 percent) appear:

Eggs deposited in fall	1,000	1,000
Loss between egg deposition and fry emergence	213	213
Loss between emergence and end of summer	740	701
Survival to end of summer	47	86

These data suggest that the loss of fry between emergence and the end of the first summer may range between 70 and 74 percent of the estimated numbers of eggs laid.

⁵ See footnote 4.

ACKNOWLEDGMENTS

Many former and present Hunt Creek staff members aided in collection of the data. Edwin L. Cooper made many of the egg counts; Lawrence H. Hazzard collected and recorded the survivors in the diver experiments; and Gaylord Alexander provided tabulations of year-class estimates from the Hunt Creek population studies. D. W. Hayne reviewed the statistical procedures, and Gerald P. Cooper and H. Eschmeyer read the manuscript and made suggestions.

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Application of the DeLury Method in Determining the Angler Harvest of Stocked Catchable-Sized Trout¹

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ABSTRACT

Creel-census data from three heavily fished California lakes are used to illustrate a method of determining the proportion of stocked catchable-sized rainbow trout, *Salmo gairdneri*, taken by anglers. This technique requires the planting of experimental lots of fish marked by the removal of designated fins. A creel checker gathers data used to estimate catch rate and fishing pressure for several days following the experimental plant. These estimates are used to determine a regression line similar to that proposed by D. B. DeLury for fish-population estimates. The regression line is used to make an estimate of the number of fish taken after the census has been terminated.

INTRODUCTION

California has the largest catchable-trout planting program in the United States. During the 1957-58 fiscal year, 13 State hatcheries produced approximately 7.5 million catchable-sized rainbow trout (*Salmo gairdneri*) at a cost of about \$1.2 million. Catchable-sized trout are defined as fish at least 10 inches long with four to six fish weighing 1 pound. The expansion of the catchable-trout program in California has been extremely rapid, and production is well ahead of evaluation. In the present paper the development of a method to determine the percentage of stocked catchable-sized trout that are harvested by anglers is reported.

The return of stocked trout to the angler has usually been estimated by complete or partial creel censuses in which marked fish are tallied as they are taken. Fish taken from given plantings are checked until returns drop to zero, at which time the percentage harvest may be readily computed. The chief advantage of this method is that a number of concurrent tests can be carried out accurately on the same water. Its main disadvantage is that it generally must be carried out at specific test sites and requires an entire season. The initial phase of California's catchable-trout evaluation project was conceived primarily with the development of a technique to estimate in a comparatively short time the percentage harvest of catchable-sized trout from many waters.

METHODS AND LIMITATIONS

During the summer of 1957, routine plantings of catchable-sized trout were marked by

removal of designated fins. The subsequent return of these fish was determined by a short-term creel census adapted from that used by Rose (1956) at Spirit Lake, Iowa. A percentage of the anglers using the test areas was interviewed, and the following parameters were estimated on each day of the census: (1) total fishing pressure (hours fished); (2) total number of marked trout taken; and (3) catch per hour for marked trout. The duration of the census on each water varied from 10 days to 1 month. Schedules were made in advance, and the census takers moved to new waters at predesignated times. Examination of the data revealed that the catch per hour of marked trout was relatively high during the first few days after stocking and decreased as the population of marked fish was reduced by angling.

Because there were limitations imposed by the seasonal time schedule, it was necessary to terminate the censuses in every instance before the marked trout had been completely harvested. This situation made it desirable to find a way to estimate the number of marked fish taken after completion of a census.

A variation of the method suggested by DeLury (1947, 1951) for the estimation of fish populations through the analysis of catch data seemed promising. In DeLury's method, catch per unit of effort is plotted against cumulative catch, with catch per unit of effort on the ordinate and cumulative catch on the abscissa. The regression line formed by the decreasing catch per unit of effort as the population becomes reduced by angling is extrapolated to intercept the abscissa, and the intercept becomes the estimate of the original population size. The regression formula is calculated by the least-squares method. DeLury proposes use of the regression method for fisheries in which natural mortality, recruit-

¹Part of Dingell-Johnson Project, California F-8-Trout Management Study."

ment, or migration do not occur. Under such conditions the total catch could eventually equal the original population. We have used this method to measure the total catch from a population of known size.

The following basic assumptions must be fulfilled for the practical application of the DeLury method: (1) the population must be closed; *i.e.*, the effects of migration, natural mortality, and recruitment must be negligible; (2) competition of gear must not occur or must be constant during the period of investigation; and (3) the catchability of the fish must remain the same during the fishing period.

The foregoing assumptions are applicable to a sport fishery where catchable trout are planted, as outlined below.

1) A plant of marked catchable-sized trout is, in effect, a closed population in which recruitment cannot occur. Planted trout generally do not migrate from lakes, although limited migration may occur in streams. A census plan can be designed to measure migration. Natural mortality can be a serious source of error in estimating original population size in some fisheries; however, such mortality may be largely ignored when dealing with catchable-trout fisheries, since the original population size is known. This assumption is particularly true when the natural mortality rate is linear or nearly so and accounts for the same fraction of available fish each day.

2) Competition of gear reduces the catch per hour in catchable-sized trout fisheries. Furthermore, such fisheries are generally quite competitive and unstable. On many waters the daily fishing pressure fluctuates considerably (Table 1). Analysis of the relations involved, however, has demonstrated that normal fluctuations in fishing pressure and the accompanying fluctuations in competition of gear will not seriously bias the estimate of percentage harvest. These relationships will be discussed fully in a later section. It is important to distinguish normal fluctuations in fishing pressure from those in which intensity of fishing effort increases or decreases steadily during the period of investigation. Changes in fishing pressure of the latter type yield data which do not show a straight-line relationship and are thus not suited for analysis by the DeLury method.

3) In catchable-sized trout fisheries, particularly in lakes, the availability of planted fish may increase for several days following

TABLE 1.—*Estimated daily fishing pressure on the Southern California lakes in 1957*

Lake Arrowhead		Lake Gregory		Green Valley	
Date	Hours fished	Date	Hours fished	Date	Hours fished
May 30	1,160	June 29	2,304	July 19	
31	444	30	2,611	20	
June 1	721	1	1,731	21	
2	764	2	1,765	22	
3	248	3	2,000	23	
4	406	4	2,209	24	
5	170	5	2,007	25	
6	202	6	2,503	26	
7	391	7	2,555	27	
8	805	8	1,623	28	
9	799	9	1,711		
10	—	10	1,427		
11	—	11	995		
12	440	12	1,513		
13	518	13	1,878		
14	441	14	1,956		
15	1,085				
16	693				
17	136				
18	337				
19	647				
20	417				
21	434				
22	893				
23	779				
24	183				
25	264				
26	239				
Total	13,516		30,788		7

liberation. This phenomenon is reflected by an increasing catch per hour and may be associated with habitat adjustment, increased hunger, the time required for distribution throughout the planted water, or other unknown factors. It is therefore necessary to begin calculation of the regression line at a point where catch per unit of effort reaches a maximum or is declining regularly.

The regression line is calculated in the manner described by Li (1957), and the pairs of *X* and *Y* values (cumulative catch and catch per hour) for these calculations is determined in the following manner. If the catch is 50 fish and the catch per hour 0.5 on the first day of census, the assigned *X* value (cumulative catch) would be 50 rather than 100, since theoretically the catch per hour is slightly higher before 50 fish are taken and slightly lower after 50 fish are taken. Should 90 fish be caught on the second day, the *X* value would be 145 (the cumulative catch on the first day plus one-half the catch on the second day).

Fluctuating fishing pressure and its subsequent effect on the accuracy of the regression line have been demonstrated (Figure 1). In a hypothetical catchable-trout fishery in which fishing pressure fluctuates from 50 hours to 250 hours on alternate days is depicted a daily harvest rates of 0.125 and 0.250,

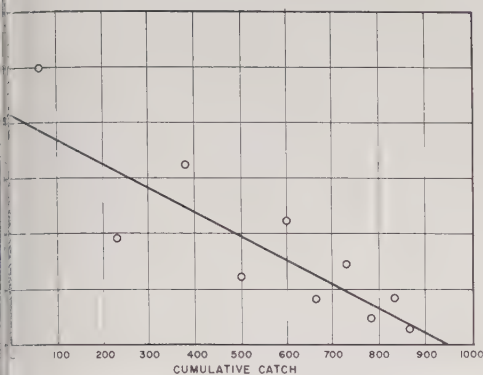


FIGURE 1.—Graphic representation of a hypothetical catchable-trout fishery in which fishing pressure increases from 50 hours to 250 hours on alternate

tively, have been assigned. The selected values, although somewhat arbitrary, are based on relationships between extent of fishing pressure and harvest rate which have actually been observed. It will be noted that a five-percent increase in fishing pressure results in a doubling of the daily harvest rate, indicating that competition of gear increases greatly when fishing pressure is substantially increased. Table 2 depicts the method by which the coordinates in Figure 1 were calculated.

The regression line in Figure 1 is based on a plant of 1,000 fish and a natural mortality rate of zero. Under such conditions, 94.5 percent of the plant will be taken by trawlers. Calculation of the regression line indicates a harvest of 94.5 percent of the experimental plant, an underestimate of 5.5 percent. The line given is described by the formula $Y = 2.16 - 0.002285 X$.

It will be noted that two distinct trends are indicated when these abstract data are used, and that the regression follows a course midway between the two extremes. The intersection

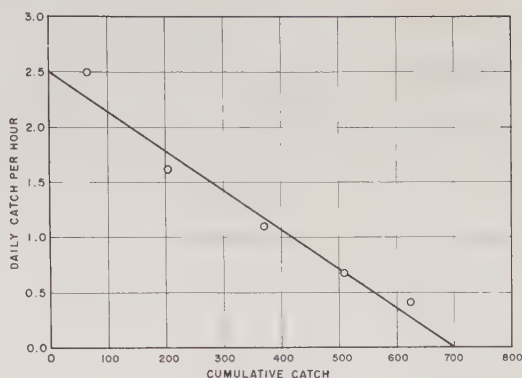


FIGURE 2.—Graphic representation of a hypothetical catchable-trout fishery in which daily fishing pressure increases by 50-hour increments from 50 hours to 250 hours in 5 days.

of the regression line with the abscissa approximates that of a fishery in which pressure is stable. Since the fluctuations given are larger than those which occur in most natural fisheries, it may be concluded that fluctuating pressure of this nature will not in itself cause serious error.

The most important sources of error in estimating total harvest, aside from those which stem from an inadequate or improper census, are (1) a steadily increasing or decreasing fishing pressure during the census period; (2) a nonlinear natural mortality rate; and (3) changes in the catchability of the experimental fish, resulting from changes in the aquatic environment.

The errors created by steadily increasing or decreasing fishing pressure may be extremely large. Figure 2 depicts a hypothetical catchable-trout fishery in which the fishing pressure is 50 hours on the first day and increases by 50-hour increments each day thereafter. The harvest rates assigned on each day are, respectively, 0.125, 0.18, 0.22, 0.24, and 0.25. The calculations are based upon an experi-

TABLE 2.—Tabulations concerning the calculation of X and Y ordinates in Figure 1

Pressure in hours	Harvest rate	Catch	Cumulative catch	Value of X	Fish remaining	Catch per hour (Y)
50	0.125	125	125	62	875	2.50
250	0.250	219	344	229	656	0.88
50	0.125	82	426	385	574	1.64
250	0.250	144	570	498	430	0.58
50	0.125	54	624	597	376	1.08
250	0.250	94	718	671	282	0.38
50	0.125	35	753	738	247	0.70
250	0.250	62	815	784	185	0.25
50	0.125	23	838	827	162	0.46
250	0.250	40	878	858	122	0.16

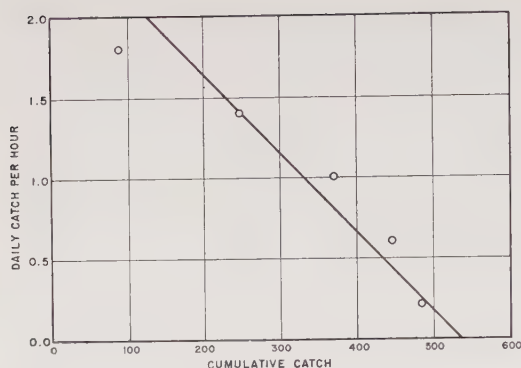


FIGURE 3.—Graphic representation of a hypothetical catchable-trout fishery in which the daily natural mortality increases from 0 percent on the first day to 10 percent on the second day, 25 percent on the third day, 50 percent on the fourth day, and 75 percent on the fifth day.

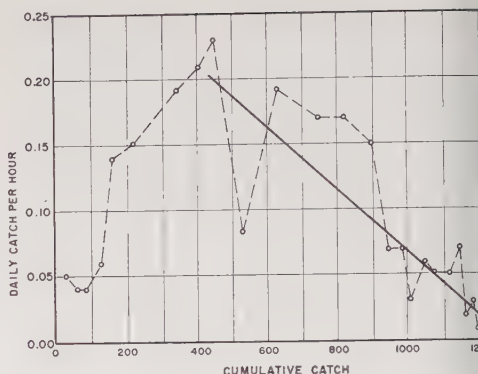


FIGURE 4.—Graphic representation of relation between catch per unit of effort and cumulative catch (dash line) provided by a plant of 3,000 catchable-sized rainbow trout in Lake Arrowhead. The regression line (solid line) is indicated. Each dot on the dash line represents one day of census.

mental planting of 1,000 fish and a natural mortality rate of zero. Under such conditions we may expect a harvest of 100 percent of the planted fish. The regression line, however, indicates a take of 701 fish from the experimental plant, an underestimate of about 30 percent. The line shown is described by the formula $Y = 2.5 - 0.003567 X$.

A nonlinear natural mortality rate is a second source of bias. Figure 3 depicts a hypothetical catchable-trout fishery in which the natural mortality rate is 0 percent on the first day, 10 percent on the second day, 25 percent on the third day, 50 percent on the fourth day, and 75 percent on the fifth day. A daily fishing mortality rate of 0.18 has been assigned. The calculations are based on an experimental planting of 1,000 fish. The error introduced by these extreme conditions is less than 10 percent of the true value. The regression line in Figure 3 is described by the formula $Y = 2.57 - 0.004803 X$. Although a nonlinear natural mortality rate will bias the estimate of percentage harvest, we may conclude that the errors created should not be excessive under most conditions.

Changes in the environment which have pronounced effects upon the catchability of the experimental fish may cause serious errors in the estimates of percentage harvest. Algal blooms, increases or decreases in turbidity, and many other physical or biological changes may affect the catchability of the experimental fish. For this reason the method should not be used during the occurrence of pronounced changes in the environment.

SPECIFIC EXAMPLES

Lake Arrowhead in San Bernardino County, which was stocked with experimental rainbow trout during the summer of 1957, is an artificial impoundment with a surface area of 100 acres and a maximum depth of 150 feet. The fishing pressure is moderately heavy with an average of 0.66 angler hour per acre per day during the census period. Three thousand marked catchable-sized trout were liberated in the lake on the evening of May 29, 1957. The catch was then intensively censused from June 30 through June 9, and from June 12 through June 26. Estimates of catch and catch per hour for the two weekdays missed (June 10 and June 11) were obtained from the mean of these values for the other three weekdays (June 12, 13, and 14). The data obtained from this census were plotted in graphic form and a regression line was calculated (Figure 4). It was estimated from the regression line that 1,261 fish from this plant (42.0 percent) were taken by anglers.² The regression line is described by the formula $Y = 0.30 - 0.000230 X$.

A similar experiment was carried out in nearby Lake Gregory, also in San Bernardino County. This 100-acre reservoir was fished at the rate of 20 angler hours per acre per day during the period of investigation. A planting of 2,800 catchable-sized trout was made on the evening of June 28, 1957, and a cen-

² For any given water the harvest from different plants varies somewhat. Further studies would be required to determine whether or not the 42 percent return indicated by this one census is representative of the entire season at Lake Arrowhead.

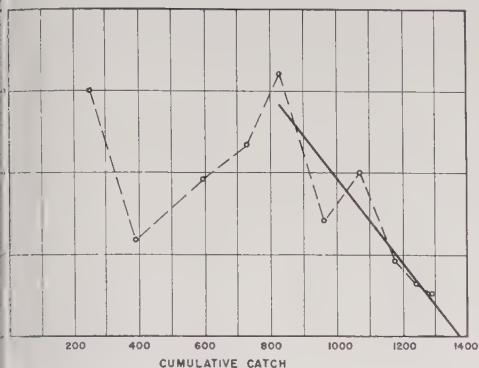


FIGURE 5.—Graphic representation of relationship between catch per unit of effort and cumulative catch (dash line) provided by a plant of 2,800 catchable-sized rainbow trout in Lake Gregory. The regression line (solid line) is indicated. Each dot along the dash line represents one day of census.

conducted during the next 15 days. The regression line ($Y = 0.25 - 0.000108 X$) indicated an estimated harvest of 83.0 percent of the planting (Figure 5).

A similar study was made at Green Valley Lake, San Bernardino County. This 12-acre lake was fished at a rate of 62 angler hours per acre per day during the census period. The catch from a planting of 1,400 catchable-sized trout made on July 18, 1957, was intensively checked from July 19 through July 28. The fish were stocked about 1:00 p.m. on July 18 and an unknown number were taken that day. For illustrative purposes it was assumed that 100 fish were taken on July 18 (Figure 6). A 98.1 percent harvest from this plant was estimated from the regression line ($Y = 0.72 - 0.000525 X$). It will be noted that the catchability of the experimental fish decreased for varying lengths of time following each planting in the three waters studied. It was therefore necessary to derive the regression line from a point where catch per unit was declining regularly.

CONCLUSIONS

The DeLury method is well suited to the majority of California's typical catchable-sized waters. The physical and biological aspects of these lakes and streams are relatively stable during the summer months when plant-fishing activity is at its height. Generally, these waters are readily accessible and adequate

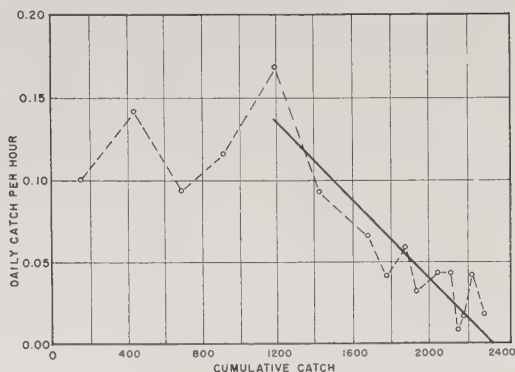


FIGURE 6.—Graphic representation of relationship between catch per unit of effort and cumulative catch (dash line) provided by a plant of 1,400 catchable-sized rainbow trout in Green Valley Lake. The regression line (solid line) is indicated. Each dot along the dash line represents one day of census.

censuses are easily designed. Heavy fishing pressure assures the gathering of sufficient data to make reliable estimates of those parameters needed to calculate the regression line.

Lightly fished lakes and streams, where returns are prolonged over many months or even years, do not lend themselves to ready analysis by the DeLury method. Aside from the obvious difficulty and expense of obtaining sufficient data for the calculations involved, physical and biological changes in the environment over long periods of time may seriously bias the results obtained.

ACKNOWLEDGMENTS

The writer wishes to acknowledge the work of Gene Beeman, who supervised much of the field work, and E. A. Friedrichsen, who provided the experimental fish. The direction and leadership of the catchable-trout evaluation project was provided by Robert L. Butler. Special thanks are due Cliffa Corson who prepared the figures and Leo Shapovalov who reviewed the final manuscript.

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Acute Toxicity of Some Organic Insecticides to Three Species of Salmonids and to the Threespine Stickleback

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ABSTRACT

The toxicity of several organic insecticides to coho (*Oncorhynchus kisutch*) and chinook salmon (*O. tshawytscha*), rainbow trout (*Salmo gairdneri*), and the threespine stickleback (*Gasterosteus aculeatus*) was determined. Toxaphene, aldrin, dieldrin, DDT, lindane, methoxychlor, heptachlor, chlordane, endrin, Guthion, malathion, Co-Ral, and Sevin were tested. Toxicity was determined at 20° C. in standing water bioassays which lasted 96 hours. Endrin was the most toxic substance tested; the 96-hour median tolerance limit (TL_m) for coho salmon was 0.51 parts per billion. With the exception of Co-Ral and Sevin, the 96-hour TL_m values of all insecticides tested were near 100 parts per billion (0.1 p.p.m.), or much less. The toxicity of the insecticides to threespine sticklebacks in waters of 5 and 25 parts per thousand salinity was not markedly different at the two salinities.

INTRODUCTION

Studies of some biological effects of organic insecticides that are sometimes introduced into water supplies have been carried on for several years at the Cincinnati, Ohio, laboratories of the Robert A. Taft Sanitary Engineering Center of the Public Health Service. Particular attention has been paid to the toxicity of these compounds to fish (Doudoroff, Katz, and Tarzwell, 1953; Tarzwell and Henderson, 1957; Henderson and Pickering, 1958; Henderson, Pickering, and Tarzwell, 1959, 1960). Species used in those studies were the fathead minnow (*Pimephales promelas*), the bluegill (*Lepomis macrochirus*), the goldfish (*Carassius auratus*), and the guppy (*Lebistes reticulatus*). Additional toxicity bioassays with other fish species were undertaken at the Pacific Cooperative Water Pollution and Fisheries Research Laboratories, Oregon State College, Corvallis, Oregon. In the present paper, estimates of the acute toxicity of 13 organic insecticides to coho and chinook salmon (*Oncorhynchus kisutch* and *O. tshawytscha*), rainbow trout (*Salmo gairdneri*), and the threespine stickleback (*Gasterosteus aculeatus*) are reported.

MATERIALS AND METHODS

Fish used in these tests were spring chinook and coho salmon and rainbow trout, all of age-group 0, and adult threespine sticklebacks. The chinooks were obtained from the McKenzie Salmon Hatchery of the Oregon Fish Commission. The coho salmon were wild fish

collected from the headwaters of the Yaquina River in Lincoln County, Oregon. Rainbow trout were from the Roaring River Hatchery of the Oregon Game Commission. Sticklebacks were from tidal sloughs adjacent to Yaquina Bay, Oregon. Chinooks ranged in size from 2 to 4½ inches total length, their weight ranged from 1.45 to 5 grams. Cohos ranged from 2¼ to 3 inches total length and from 2.7 to 4.1 grams in weight. Rainbows varied from 2 to 3½ inches total length and averaged 3.2 grams in weight. Sticklebacks were from ⅞ to 1¼ inches total length and weighed from 0.38 to 0.77 grams. Tests with chinooks were carried on from May through August 1959, with cohos from August to November 1959, with sticklebacks from February to May 1960, and with rainbow trout from May through June 1960.

The salmonids were kept outdoors in wooden tanks which were supplied with running water from a small spring-fed stream. Several times each week the fish were fed a diet consisting of liver, horsemeat, trout, whole marine fish, and cereals. Before use in a bioassay, the salmon were brought into a constant temperature room to acclimate them overnight to the experimental temperature (20° ± 0.5° C.). Sticklebacks were selected as required and were kept in the constant temperature room without feeding.

The tests were conducted according to methods outlined by Doudoroff *et al.* (1951) with a notable deviation which was necessitated by the high rate of oxygen consumption by the test fish and the considerable biochemical oxygen demand of the acetone which was used to dissolve the insecticides. Because the oxygen level of the test aquaria could not

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TABLE 1.—Estimated median tolerance limits (TL_m) of some insecticides for chinook salmon, coho salmon, and rainbow trout

[Expressed in parts per billion active ingredient]

Insecticide	Chinook salmon				Coho salmon					Rainbow trout			
	Hours				Hours					Hours			
	24	48	72	96	24	48	72	96		24	48	72	96
Phenanthrene	7.9	3.3	2.7	2.5	13.0	10.5	10.0	9.4		11.5	8.4	8.4	8.4
Dieldrin	12.4	10.6	8.7	7.5	—	61.0	48.6	45.9		42.4	23.9	20.3	17.7
Endrin	7.9	6.7	6.1	6.1	17.5	15.3	14.4	10.8		15.7	13.0	9.9	9.9
Chlordane	38.0	17.0	14.0	11.5	66.0	46.0	44.0	44.0		42.0	42.0	42.0	42.0
Lindane	56.0	42.0	42.0	40.0	60.0	56.0	56.0	50.0		42.0	41.0	39.0	38.0
Methoxychlor	28.0	27.9	27.9	27.9	66.2	66.2	66.2	66.2		62.6	62.6	62.6	62.6
Toxaphene	32.4	26.6	23.0	17.3	61.9	60.4	60.4	59.0		36.7	33.8	25.9	19.4
Heptachlor	59.0	59.0	57.0	57.0	100.0	86.0	82.0	56.0		56.0	44.0	44.0	44.0
DDT	2.0	1.2	1.2	1.2	1.3	0.8	0.52	0.51		0.79	0.58	0.58	0.58
Guthion	6.8	6.2	4.3	4.3	7.0	5.0	4.8	4.2		4.7	3.8	3.8	3.2
Malathion	24.5	23.9	23.6	23.0	—	—	—	—		—	—	—	—
Co-Ral	—	—	—	—	22,000.0	20,000.0	18,000.0	15,000.0		—	1,800.0	1,500.0	1,500.0
	—	—	—	—	1,330.0	997.0	997.0	997.0		—	1,600.0	1,350.0	1,350.0

maintained adequately by surface reaeration, test solutions were aerated with compressed air. Glass tubing of 7 millimeters inner diameter was used to introduce the air into the test aquaria. The tubes could be removed at the end of each test and cleaned thoroughly. There was no indication that aeration changed the toxicity of the toxicant solutions.

The insecticides were introduced into 15 liters of water taken from the same source as the water in which the fish were held. The values of the diluent water varied between 6.5 and 7.4 but usually were near the higher end. Total alkalinity as CaCO_3 varied between 45 and 57 p.p.m. The diluent water was stored in the constant temperature room for 3 to 14 days before use. Test aquaria were 5-gallon wide-mouth glass jars.

Three to five salmonids were tested in each jar, while 11 to 20 sticklebacks were tested per jar. The numbers of test fish per jar varied to insure that not more than 1 liter of fish per liter of water was present. Up to 20 fish were used at each concentration of toxicant at which some fish survived 48 hours or more. To conserve experimental fish, only five fish were used at the concentrations at which all fish survived for 48 hours or at which all died within the first 48 hours in the initial tests. Test concentrations were selected in accordance with Table 1 of Doudoroff *et al.* (1951). Each compound was tested in replicate during successive weeks with different samples of fish. Tests were terminated at the end of 96 hours. The insecticides tested included nine chlorinated hydrocarbon compounds, three organic

phosphorus compounds, and one carbamate. The formulations of chlorinated hydrocarbons were:

Aldrin, technical—88.4 percent aldrin, 4.6 percent related compounds;

Dieldrin, technical—90 percent dieldrin;

Endrin, purified—98.2 percent endrin;

Chlordane, reference standard—100 percent chlordane;

Heptachlor, technical—72 percent heptachlor, 28 percent related compounds;

Methoxychlor—89.5 percent p, p' isomer;

Toxaphene, reference standard—highest purity, containing 67–69 percent chlorine;

DDT, reference standard—pure p, p' isomer; and

Lindane—100 percent lindane.

The insecticides used in this study, with the exception of the endrin, were sent to the author by Crosswell Henderson (R. A. Taft Sanitary Engineering Center, Cincinnati) and were subsamples of the toxicants used in the bioassays reported by Henderson *et al.* (1959). Their chemical composition and useful physical properties are adequately discussed by those authors and in published material distributed by manufacturers.

The organic phosphorus compounds tested were malathion, Guthion, and Co-Ral. The formulations tested, the active ingredients, and the compositions of these compounds were:

Malathion—57 percent malathion, 43 percent inert ingredients. (The chemical formulation and pertinent physical properties are discussed in some detail by Henderson and Pickering, 1958).

Guthion, technical—93 percent active ingredient. Chemical name: O,O-dimethyl

TABLE 2.—The 96-hour median tolerance limits of some insecticides for rainbow trout, chinook salmon, salmon, fathead minnow, bluegill, goldfish, and guppy

[Expressed in parts per billion active ingredient]

Insecticide	Chinook salmon	Coho salmon	Rainbow trout	Fathead minnow ¹	Bluegill ¹	Goldfish ¹	Guppy
Toxaphene	2.5	9.4	8.4	7.5	3.5	5.6	
Aldrin	7.5	45.9	17.7	33.0	13.0	28.0	
Dieldrin	6.1	10.8	9.9	16.0	7.9	37.0	
DDT	11.5	44.0	42.0	32.0	16.0	27.0	
Lindane	40.0	50.0	38.0	62.0	77.0	152.0	
Methoxychlor	27.9	66.2	62.6	64.0	62.0	56.0	
Heptachlor	17.3	59.0	19.4	94.0	19.0	230.0	
Chlordane	57.0	56.0	44.0	52.0	22.0	82.0	
Endrin	1.2	0.51	0.58	1.0	0.6	1.9	
Malathion	23.0	—	—	12,500.0 ²	95.0 ³	—	
Co-Ral	—	15,000.0	1,500.0	18,000.0 ³	180.0 ³	—	
Sevin	—	997.0	1,350.0	6,700.0 ³	5,300.0 ³	—	
Guthion	4.3	4.2	3.2	93.0 ³	5.2 ³	—	

¹ Henderson *et al.* (1959), unless otherwise designated.² Henderson and Pickering (1958).³ Henderson *et al.* (1960).

S-(4-oxo-1, 2, 3-benzotriazinyl-3-methyl) phosphoro-dithionate. Properties: solid, soluble in water at approximately 1:30,000, soluble in many organic solvents.²

Co-Ral—98 percent active ingredient. Chemical name: O,O-diethyl O-(3-chloro-4-methylumbelliferone) phosphorothionate. Properties: white crystalline powder with characteristic pungent odor, slightly soluble in water and readily soluble in acetone (O'Brien and Wolfe, 1959).

Sevin, which was also tested, may be classed as a carbamate. The following information about Sevin is available:

Sevin—95 percent active ingredient. Chemical name: N-methyl-1-naphthyl carbamate. Properties: slightly colored, light to lavender, nearly odorless, crystalline, solubility less than 0.1 percent in water.³

Stock solutions of the above insecticides were prepared by dissolving 100 milligrams of the toxicant to a volume of 100 milliliters with pure acetone. In order to make accurate dilutions of a compound which was highly toxic to fish, a weaker stock solution was prepared by diluting 1 milliliter of the original stock solution to 100 milliliters with pure acetone. The only exception to the above procedures was with Co-Ral, of which some test solutions were prepared by adding weighed

amounts of the insecticide directly to the water in the test aquaria.

Control aquaria contained water to which was added the largest amount of acetone used in any experiment in the bioassay series. No mortalities were observed in the control. The experimental data are expressed in parts per billion of the active ingredient. No attempt was made to test any of the special formulations commonly used in insect-control procedures.

RESULTS AND DISCUSSION

The estimated median tolerance limits (TL_m) for chinook and coho salmon and rainbow trout fingerlings of the insecticides tested are listed in Table 1. The 24-, 48-, 72-, and 96-hour median tolerance limits of the insecticides are expressed in parts per billion (p.p.b.) of active ingredient. The 96-hour TL_m estimates for chinook and coho salmon and rainbow trout are listed in Table 2, along with the estimates obtained by Henderson *et al.* (1959) and by Henderson and Pickering (1958) for warm-water and aquarium species. The median tolerance limits (TL_m) for mummichog and threespine sticklebacks in salinities of 5 and 25 parts per thousand are listed in Table 3.

Of the compounds tested, endrin was consistently the most toxic to all species of fish, with a 96-hour TL_m for chinooks of 0.6 p.p.b., for cohos of 0.51 p.p.b., and for rainbow trout of 0.58 p.p.b. Co-Ral is the least toxic of the compounds tested, with an estimated 96-hour TL_m of about 15,000 p.p.b. for cohos and 1,500 p.p.b. for rainbows. In general, the cohos and rainbows were more

² Chemagro Corporation. (1957) Guthion. New York 16, New York.

³ Union Carbide and Chemicals Company. (1958) Technical information on Sevin for research workers. New York 17, New York. 12 pp.

TABLE 3.—Estimated median tolerance limits for sticklebacks of some insecticides in waters of 5 and 25 parts per thousand salinity

[Expressed in parts per billion active ingredient]

Insecticide	5 parts per thousand salinity				25 parts per thousand salinity			
	24	48	72	96	24	48	72	96
DDT	—	12	9.8	8.6	—	—	8.8	7.8
Endrin	—	48.3	41.5	39.8	—	44.2	27.4	27.4
Aldrin	20.7	18.9	18.0	15.3	—	—	13.5	13.1
	22.0	21.0	18.5	18.0	18.0	15.0	14.5	11.5
Dieldrin	50.5	45.0	45.0	44.0	66.0	51.0	50.0	50.0
Chlorobenzene	93.6	86.4	86.4	86.4	—	69.1	69.1	69.1
Chlorpyrifos	120.8	111.9	111.9	111.9	111.9	111.9	111.9	111.9
Permethrin	118.0	118.0	90.0	90.0	180.0	170.0	170.0	160.0
Sevin	—	0.45	0.45	0.44	—	—	0.58	0.50
Malathion	15.8	15.8	14.9	12.1	6.9	5.0	4.8	4.8
Guthion	96.9	94.0	94.0	94.0	76.9	76.9	76.9	76.9
Co-Ral	—	2,254.0	1,862.0	1,862.0	—	1,764.0	1,568.0	1,470.0
Endosulfan	—	16,625.0	6,175.0	3,990.0	—	10,450.0	4,940.0	3,990.0

tant to most of the insecticides tested than the chinooks. Chinooks were more tolerant to endrin than were the cohos and rainbows, but the difference was minor. The differences in tolerance of the three species to most of the insecticides are not large.

A comparison of the 96-hour TL_m estimates for the salmonids with the data obtained by Anderson *et al.* (1959) and Henderson and Kester (1958) shows that the salmonids, especially chinook salmon, were usually somewhat more sensitive than the warm-water and aquarium species, although the salmonids were tested at 20° C. instead of 25° C., at which warm-water species were tested.

Coho salmon were able to tolerate relatively low concentrations of Co-Ral and Sevin, with respective 96-hour TL_m values being 15,000 and 997 p.p.b. These data suggest that useful insecticides can be developed that would not be highly toxic to fish. Co-Ral, which is the most toxic of the compounds tested, is used principally as a systemically active insecticide and is in no sense, at least at present, a replacement for the more versatile insecticides. Endrin, with a 96-hour TL_m for coho salmon of about 1,000 p.p.b., is reported to have a wide spectrum of insecticidal activity. This compound therefore might be suggested as a substitute for substances of pronounced lethality to fish in insect-control programs where possible damage to fish populations is a consideration.

No insecticide differed much in its toxicity to sticklebacks in water of 5 and 25 parts per thousand salinity. Eight of the 13 substances tested were slightly more toxic, while three substances were slightly less toxic in the more

saline water. The greatest difference was noted in the case of Guthion. The median tolerance limits obtained with the marine sticklebacks at salinities of 5 and 25 parts per thousand (Table 3) did not show any striking differences from the data obtained with the salmonids in fresh water.

Those who may wish to use these data as a guide in planning an insecticide spraying program should exercise some caution. The termination of these experiments at 96 hours does not imply that no deaths would occur after this period. For example, no mortalities were observed at concentrations of 10,000 p.p.b. Co-Ral at the end of the 4-day test period. The fish were allowed to remain in the toxicant solution for 5 additional days, and at the end of the 9-day period, all of the fish had died. There were instances of similar delay of mortality with some other insecticides, particularly endrin.

Weiss (1959) showed convincingly that the known undesirable effect of some organic phosphorus insecticides (*i.e.*, the inhibition of acetylcholinesterase activity) persists as long as 45 days after contact in some fish. Even if mortalities do not occur following insecticide applications, the depression of normal activity patterns may make some fish unable to carry on their functions with the competitive efficiency required for survival in their natural environment.

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Biology of the Utah Chub in Hebgen Lake, Montana¹

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ABSTRACT

The Utah chub, *Gila atraria*, was probably introduced into Hebgen Lake, Montana, in 1935 by bait fishermen. Randomly set gill nets indicate that chubs are concentrated in shallow areas in the spring, widely distributed in the summer and fall, and concentrated in deeper waters in winter. Stomach analyses of 165 chubs collected during the summer of 1948 show that by volume the food was 48.2 percent algae, 21.1 percent higher aquatic plants, and 24.3 percent microcrustaceans. The 209 stomachs taken in 1953-54 contained 36 percent insects, 36 percent microcrustaceans, 19 percent higher aquatic plants, and 9 percent debris. The peak of the spawning season in 1953 and 1954 occurred during late June and early July. Most spawning occurred when water temperatures were above 54° F. Eggs were found on different kinds of bottom, but most were recovered from sand and gravel. The average number of eggs per female was 40,750. Fry occurred along most of the shallow protected shorelines. Fry captured on July 7, 1954, averaged 0.3 inch in total length. Young taken October 1, 1943, averaged 1.3 inches. No mature males less than 3 years old or mature females less than 4 were found. Total lengths for the first 8 years of life were calculated on 475 specimens.

INTRODUCTION

The Utah chub, *Gila atraria* (Girard), is native to the Bonneville Basin of Utah and the Snake River drainage of Wyoming and Idaho (Simon, 1946). It is presumed that this species was accidentally introduced into Hebgen Lake, Montana, by live-bait fishermen. Local residents report that schools of minnows, believed to be Utah chub, were first observed during the thirties (1935-37). Chubs rapidly became more abundant and probably reached maximum abundance about 1938. They have remained at a high level since that time. Chubs have been collected in tributaries several miles above Hebgen Lake. Their downstream range below the lake includes all of the Madison River, and they may also be present in its tributaries. The chub is a poor food source and is a nuisance to the fisherman because it readily takes most trout baits. Davis (1940) and Sigler (1935) report that a decline of the trout fishery in Fish Lake, Utah, appeared to be associated with an increase in abundance of the Utah chub, but limited data from Hebgen Lake do not indicate a similar relationship.

Information on the biology of the Utah chub was necessary in order to develop a fish-management program for Hebgen Lake. Preliminary investigations on abundance and habits made in 1948 by R. A. Hayes and

C. G. Bishop of the Montana Fish and Game Department and more intensive work on the biology conducted during 1953-54 by the writer are presented herein.

Hebgen Lake is an artificial impoundment (Figure 1) created in 1914 and located on the Madison River in Gallatin County, approximately 1 mile west of Yellowstone National Park. Its principal tributaries are Madison River, South Fork of Madison River, Grayling Creek, and Duck Creek—all of which arise in Yellowstone National Park. Most of the land around the lake is in the Gallatin National Forest and is used principally for recreation. The dam which impounds Hebgen Lake has a spillway elevation of 6,544 feet (mean sea level). The reservoir has a capacity of 344,730 acre feet, a surface area of 13,700 acres, and a maximum depth of 61.5 feet. Maximum recorded water temperature at the surface is 76° F. Ice usually forms during the latter part of October or early November and disappears in late April or early May. Methyl orange alkalinity was 77 p.p.m. and pH was 7.2 (November 11, 1954).

Prior to 1953 water was stored in Hebgen Lake during the spring and summer and released during fall and winter. Since 1953 water has been released rapidly in the fall so that the minimum level is usually reached in November. In a normal year the lake level is lowered about 17 feet and the volume reduced to 160,000 acre feet.

The Utah chub is the most abundant fish in Hebgen Lake. Brown trout (*Salmo trutta*) and mountain whitefish (*Prosopium williamsi*) rank next and are followed by rain-

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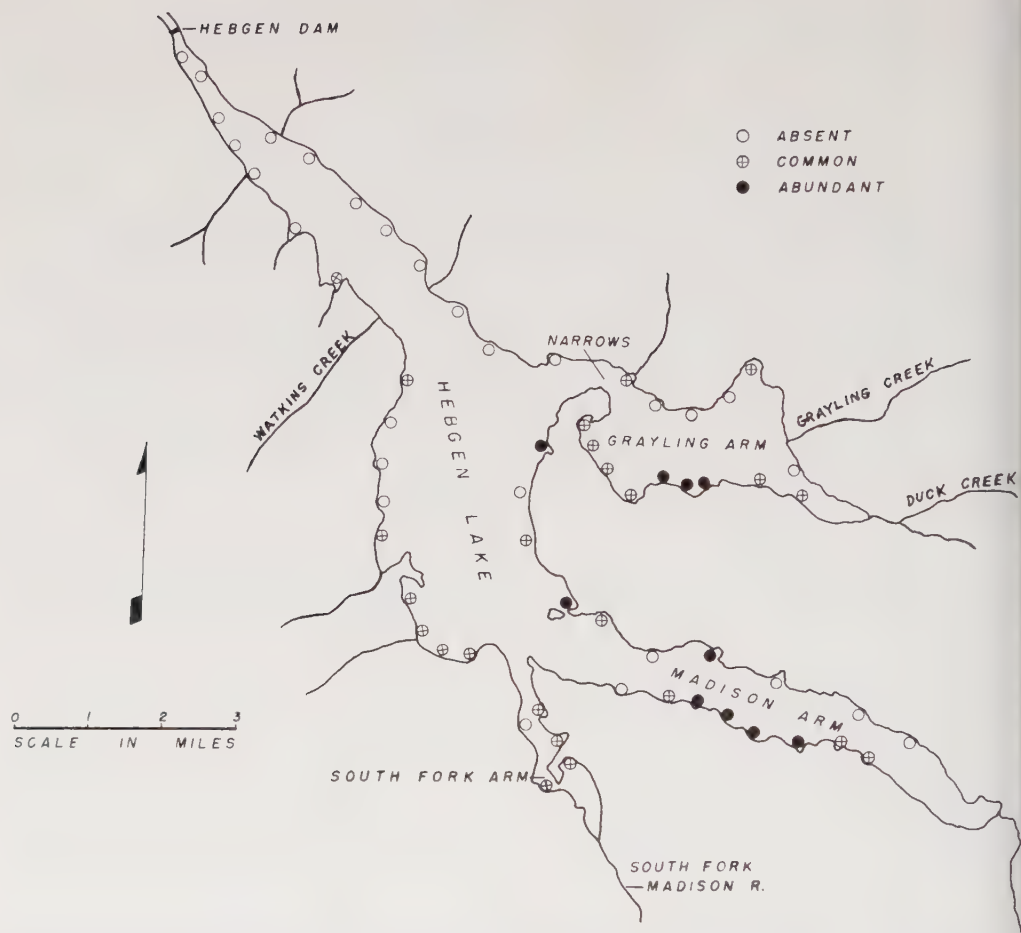


FIGURE 1.—Map of Hebgen Lake showing the distribution and general abundance of Utah chub from 1953-54.

bow trout (*Salmo gairdneri*). Cutthroat trout (*Salmo clarki*), brook trout (*Salvelinus fontinalis*), Arctic grayling (*Thymallus arcticus*), longnose sucker (*Catostomus catostomus*), longnose dace (*Rhinichthys cataractae*), and mottled sculpin (*Cottus bairdi*) occur in limited numbers.

Most observations and collections were made in the shallow areas of the lake, particularly the Grayling and Madison arms. Grayling arm is connected to the main lake by a short channel called "The Narrows" (Figure 1). Most of the arm has a depth of less than 15 feet, and during the winter it is almost completely drained. The principal bottom material is muck, although sand and gravel are present along the southern shoreline. The entire arm supported an extensive growth of aquatic vegetation in 1948. Pondweeds (*Potamogeton*

gramineus, *P. pectinatus*, *P. richardsonii*), water ladysthumb (*Polygonum amphibium*), water crowfoot (*Ranunculus trichophyllus*), American milfoil (*Myriophyllum exalbescentum*), and several algae were common. Local residents report that aquatic vegetation became much reduced during the following 2 years. By 1953 only scattered patches were found, mainly along the southern shoreline. Madison arm is about 5 miles long and 1 mile wide. More than half of the arm has a depth of less than 15 feet. The bottom is primarily sand and gravel. All plant species listed above were present, but pondweeds were rare and abundant.

ABUNDANCE AND DISTRIBUTION

Fish collections, except for fry and finlings, were made with 125-foot graded

TABLE 1.—Fish captured in Hebgen Lake by 125-foot gill nets set at random in 1948 and set selectively in 1953–54

	Species	Total number	Percentage of total	Catch per hour
1948	Utah chub	708	72.5	7.3
	Whitefish	147	15.1	1.5
	Brown trout	79	8.1	0.8
	Rainbow	31	3.2	0.3
	Cutthroat	6	0.6	—
	Grayling	3	0.3	—
	Sucker	2	0.2	—
1953	Utah chub	1,030	91.9	8.3
	Whitefish	26	2.4	0.2
	Brown trout	54	4.8	0.4
	Rainbow	10	0.9	0.1
1954	Utah chub	4,595	90.2	6.4
	Whitefish	210	4.1	0.3
	Brown trout	265	5.2	0.4
	Rainbow	25	0.5	—
	Grayling	1	—	—

1949 sets, average time per set 2.0 hours, set mostly during the morning.

1948 sets, average time per set 2.9 hours, set mostly during the morning.

1950 sets, average time per set 8.0 hours, set mostly overnight.

3/4–2 inches bar mesh). In 1948 gill nets were set at random throughout the lake from May 13 to September 21. The comparative abundance of the various species was estimated from these collections (Table 1). The netting operations of 1953 and 1954 were confined to areas where chubs were known to be abundant. Over 75 percent of the 1953–54 sets were made in the Madison and Grayling arms during June and July and at depths of less than 10 feet. Collections were not comparable between any 2 years with respect to catch per hour or species composition.

The Utah chub was the most abundant species in the 1948 collections. In 1953 and 1954 the percentage of chubs was considerably greater, but this increase was undoubtedly due to selection of sites for setting of nets. The catch per hour for chubs was 7.3 in 1948, 8.3 in 1953, and 6.4 in 1954. In 1953 the larger catch per hour was probably due to selection of gill-netting sites. The average time for sets in 1954 was three to four times greater than in 1948 or 1953. This difference probably accounts for the smaller catch per hour since the sets set overnight frequently became so full of fish their efficiency was reduced.

Netting in 1948 indicated that the greatest concentration of chubs was in the Grayling arm. In 1954, 44 sets were made in the Madison arm and 39 in the Grayling arm. The catch per hour for chubs was 6.0 and 7.3 respectively.

Although no careful study of the seasonal distribution of the Utah chub in Hebgen Lake

was made, some general trends were discernible. The adult chubs apparently move from the deeper parts of the lake into shallower areas when the ice disappears and the water level rises. On May 5, 1954, a shallow set at the Narrows in Grayling arm caught only trout and whitefish. At this time most of the lake was covered with ice. On May 23, after ice had disappeared, nets placed in the same area took many chubs. Chubs were abundant in shallow areas throughout the summer, but the catch showed a decline in early July, 1954. At this time most of the chubs had completed spawning, and many small schools of adults were observed moving along the shoreline. Resort owners near the deeper areas of the lake report that chubs are seldom observed until early July. During midsummer large schools were observed by the writer and reported by local residents in widely scattered parts of the lake. Chubs were present in shallow areas through September and October. On November 11, 1954 (ice was beginning to form), a net placed in the shallows of Grayling arm took whitefish but no chubs. These observations indicate that chubs are largely concentrated in deeper sections of the lake during the winter. A similar seasonal distribution was reported for the Tui chub (*Siphateles bicolor*) in Eagle Lake, California (Kimsey, 1954).

FOOD HABITS

During 1948 the stomach contents of 165 chubs, ranging from 5.3 to 14.5 inches in length, were examined. Specimens were collected by angling and gill-netting at irregular intervals during June, July, August, and September. Stomachs were immediately preserved in formalin, the contents from each stomach sorted into taxonomic groups, and the volume of each group was measured by displacement (Table 2). Food of all size groups was very similar. Algae (48.2 percent) and higher aquatic plants (21.1 percent) constituted 69.3 percent of the total food volume of all chubs. Cladocera ranked next with 24.3 percent. The combined volume of insects amounted to 0.7 percent of the total, and unidentified material and debris made up 3.6 percent of the food volume. Sigler (1953) reported that the principal food items of 90 Utah chubs from Fish Lake, Utah, were *Daphnia* and *Gammarus* with algae ranking next.

Stomachs of 209 chubs collected during the summers of 1953 and 1954 were examined.

TABLE 2.—Percentage frequency of occurrence and percentage of total volume of food items in stomachs of 165 Utah chubs taken in 1948, and 209 in 1953–54, Hebgen Lake

Item	1948		1953–54	
	Occurrence	Volume	Occurrence	Volume
Algae	31	48	7	tr. ¹
Higher aquatic plants	29	21	44	19
Nematoda	1	tr.	1	tr.
Mollusca	10	1	3	tr.
Hirudinea	1	1	—	—
Cladocera	58	24	55	36
Copepoda	8	tr.	—	—
Amphipoda	4	tr.	tr.	tr.
Odonata	—	—	tr.	tr.
Ephemeroptera	2	tr.	18	8
Homoptera	—	—	2	1
Trichoptera	—	—	5	tr.
Diptera	60	1	64	27
Coleoptera	1	tr.	tr.	tr.
Arachnoidea	16	tr.	1	tr.
Unidentified and debris	41	4	59	9

¹ tr.=trace.

Over 90 percent of the specimens were secured from gill nets set for 2 hours or less. The kinds, percentage of occurrence, and estimated percentage of volume of food of chubs are given in Table 2.

Microcrustacea and insects each constituted 36 percent of the total volume. *Daphnia* was the most important crustacean. Larvae and pupae of Diptera made up about 75 percent of the volume of insects and Ephemeroptera nymphs about 20 percent. Other orders of insects represented were Odonata, Homoptera, Trichoptera, and Coleoptera. Higher aquatic plants comprised about 19 percent and unidentified material and debris 9 percent of the total volume.

A comparison between the foods of chub taken in 1948 and those taken in 1953–54 indicated a change in diet. Approximately 65 percent of the stomachs examined in 1948 were collected in Grayling arm and in the vicinity of the Narrows. During 1953–54 approximately 70 percent of the stomachs were collected in these areas. In 1948 algae occurred in 31 percent of the stomachs and constituted about one-half of the volume, while in 1953–54 algae were found in 7 percent of the stomachs and amounted to only a trace of the volume. Insects (principally Diptera larvae and pupae) replaced algae in volume as they increased from 0.7 percent in 1948 to 36 percent in 1953–54. The change in diet probably resulted from a reduction of aquatic vegetation which occurred in these areas between the two study periods. Contrary to Jordan and Evermann (1896) who charac-

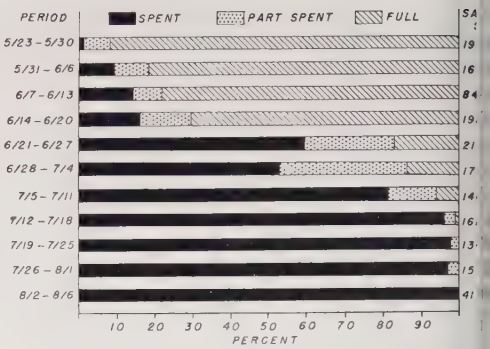


FIGURE 2.—Ovary condition of 1,666 chubs captured during the summer of 1954 in Hebgen Lake, Montana.

terized the Utah chub as “extremely destructive of other fishes, especially to young trout. No fishes of any kind were found in the stomachs of the 374 chubs studied.

SPAWNING

The gonads of all Utah chubs collected during 1953–54 were examined to determine maturity and sex. Depending upon the condition of the ovaries, the mature females were classified as follows: (1) spent—ovaries with very or no eggs; (2) partially spent—ovaries containing about one-half their egg capacity; full—ovaries full of eggs. Some very young females may have lost eggs while struggling in gill nets, but this probably was of little significance to the findings since these females would have spawned within a few days.

The 304 mature female chubs collected May 30–July 12, 1953, were classified as to the condition of their ovaries and grouped by collection periods. All females collected on May 30 were full. The proportion of spent females increased from about 33 percent (June 15–28) to about 76 percent (June 21–July 12), while the full females decreased from about 50 percent to 6 percent during the same period. Approximately 20 percent of the males taken were partially spent.

In 1954, 1,666 female chubs were collected and all except 27 were taken by gill nets. They were classified and grouped by collection periods between the dates of May 23 and August 6 (Figure 2). During the first collection period (May 23–30) only 1 percent of the captured females were spent. The number of spent females taken May 31–June 20 remained at a low level (13.5 percent) but increased to about 63 percent for periods extending from June 21 to July 11. Over 95 percent of the females collected between July 12 and August

were spent, and during the last period (August 2-6) all were spent.

The rapid rate of increase in proportion of spent females with a corresponding decrease in unspent females as the netting progressed indicates that the peaks of spawning for 1953 and 1954 were during late June and early July. The fact that in 1954 the largest percentages of partially spent females were noted between June 21 and July 11 further suggests that the peak of spawning occurs in this period. Beginning and ending dates of the 1953 spawning season were not determined. In 1954 the spawning apparently began in May and extended into August. Many ripe males were observed throughout the 1953 collecting period (May 30-July 12). In 1954 ripe males were abundant from the earliest collections (May 23-30) until mid-July, and there was no indication that males ripened sooner than females.

Two water temperature stations were established in Hebgen Lake, one in the Madison arm and the other at the Narrows. Maximum-minimum thermometers were placed about 2.5 feet below the surface, and readings were taken at irregular intervals during collecting periods. Water temperature in 1953 during the peak of spawning (June 17-July 9) averaged 60.2° F. with a maximum of 68° and a minimum of 54°. In 1954 the average water temperature was determined for periods corresponding to chub-collecting periods and then compared with the incidence of spent females (Figure 3). Average water temperatures between May 30 and June 21 were below 55° F., and the occurrence of spent females during this time remained below 20 percent. The increase in the percentage of spent females for the period June 21-27 was associated with an increase in the water temperature. Most spawning apparently occurs in water temperatures above 54° F.

Two methods were used to locate chub spawning areas: (1) observation of the fry distribution which would indicate the location of spawning areas with respect to the lake shoreline; and (2) selection of specific areas for bottom sampling to recover eggs. Information on the presence and distribution of fry was obtained by seining and observation of the shoreline during 1953-54 (Figure 1). The length of shoreline surveyed at each sampling point varied from 75 to 100 yards.

The western part of the main lake, from the mouth to Watkins Creek, is characterized by

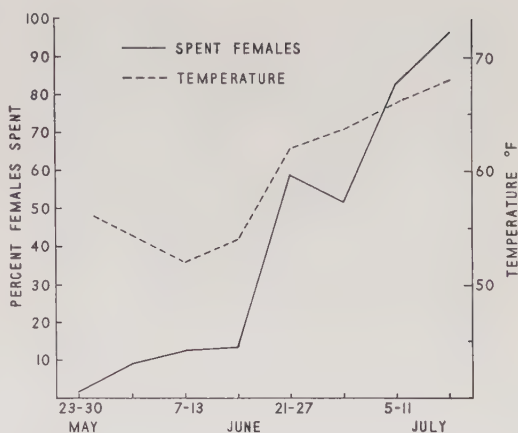


FIGURE 3.—Relationship between temperature and the percentage of spent females occurring in periodic 1954 collections in Hebgen Lake, Montana.

steeply sloping bottoms, and no fry were found there. From Watkins Creek to the South Fork arm the shore has steeply sloping bottoms interspersed with shallow areas. Here fry were locally distributed in protected areas but were never abundant. A few fry were present in several shallow bays of the South Fork arm. Fry were distributed in the numerous shallow areas along the southern shoreline of the Madison arm, and many were observed in certain of these areas. One heavy concentration of fry was found along the northern shore of the Madison arm in a protected shallow area, but fry were abundant in several protected shallow areas along the shoreline from the Madison arm to the Narrows. In the Grayling arm, fry were found along most of the southern shoreline, but heavy concentrations were confined to areas with sand and gravel bottoms. Fry were seldom found along the northern shores of this arm. In 1948, when aquatic vegetation was abundant in Grayling arm, numerous fry were observed in certain areas which had bottoms of silt and muck, but these areas had few or no fry in 1953-54 when vegetation was nearly absent. Few protected shallow areas occur between Grayling arm and the dam, and no fry were found along this shoreline.

Because southwesterly winds prevail during the summer, the northern shores of the lake are subjected to severe wave action. Fry were seldom found in such exposed areas even though other factors seemed favorable for spawning. Fry occurred along most shallow protected shorelines, and the heaviest con-

centrations were found in the Madison and Grayling arms.

In 1954 specific areas were selected for bottom sampling in an attempt to recover eggs. Chub eggs were collected by removing a thin surface layer of the bottom with a scoop or by dragging a fine-mesh insect net through bottom material stirred with the feet. Eggs were separated from bottom materials by successive washings through graded screens. No quantitative samples were taken.

Eggs were recovered from 25 of 47 bottom samples taken June 25–July 9. They were found on gravel, sand, silt, muck, and detritus bottoms, but most were recovered from sand and gravel. Eggs were found at depths of 1 to 4 feet and at distances 2 to 150 feet from shore. They were undoubtedly present at greater depths, but no samples were taken because there were limitations to the collecting methods.

Submerged plants were not abundant during the sampling period, and those present had made very little growth. No eggs were found adhering to plants. Numerous examinations of submerged snags, stumps, and brush in shallow water revealed no attached eggs. Two mats (3 by 4 feet) of woven willow branches, a piece of driftwood, and an iron pipe were placed at depths of 8 to 10 feet in areas where spawning was believed to occur. They were checked periodically during the spawning period, but no eggs were found on them. None were taken in surface plankton hauls over known spawning areas. Deposition and fertilization of eggs were not observed. No evidence was found of nest construction, and the distribution of eggs indicates that they are broadcast over the bottom.

The Montana Fish and Game Department maintained rainbow trout spawning stations on several tributaries to Hebgen Lake for many years. Traps were operated during May and June, and trap tenders reported that very few chubs were taken. No movement of chubs into tributary streams was observed during the present study.

The approximate number of eggs in seven females ranging in size from 8.8 to 13.8 inches and collected during June 1953 was determined. Numbers were calculated from the volumes of the egg sacs. The average number of eggs per female was 40,750 with a minimum of 15,900 (8.8-inch fish) and a maximum of 62,400 (13.8-inch fish).

TABLE 3.—Size of Utah chub fry and fingerling collections from Hebgen Lake, Montana

Period	Number	Total length (inches)	
		Range	Average
1953			
August	3–6	275	0.4 – 1.3
August	27–28	345	0.6 – 2.1
September	15–16	265	0.6 – 2.0
October	10	62	0.8 – 2.0
1954			
July	7–9	224	0.25 – 0.5
July	21–28	226	0.25 – 0.7
September	7–8	157	0.8 – 1.5

¹ Measurements from specimens preserved in 10-per cent formalin.

AGE AND GROWTH

The first fry were observed in 1953 August 3 (Table 3) when they ranged in total length from 0.4 to 1.3 inches with an average of 0.8. In 1954 fry were first observed on July 7, and these ranged in total length from 0.25 to 0.5 inch with an average of 0.3. Fry and fingerlings were collected from depths of 1 to 10 feet at irregular intervals from August to October in 1953 and in July and September in 1954. Fingerlings which averaged 1.3 inches in total length were collected on October 31, 1953. During late September and October fingerlings became scarce. The average total length of young of the year during these months is probably greater than indicated in the samples since larger fish apparently move into deeper water.

A collection of fry (0.8 inch total length) on October 31, 1953, suggests that at least a few chubs may not form scales during their first growing season. Scales with one to three circuli were found on fish 1.0 inch in total length. Scales were not detected on fish 1.3 inch long, but bony plates without circuli were found on several specimens with a total length of 0.9 inch. Kimsey (1954) found scales forming on *Siphateles bicolor* when standard length was 0.78–0.97 inch.

A length-frequency polygon of 189 fry and fingerlings collected from one area on August 6, 1953, indicates that two age groups were present (Figure 4). The average total length of fish in the first and second groups were 0.8 and 2.8 inches, respectively, and scales were present on fish in the second group showed them to be yearlings.

Total lengths of mature male, mature female, and immature chubs collected by gill netting in 1954 were determined (Figure 5). Fish with undeveloped gonads were classified as immature and were not sexed. The

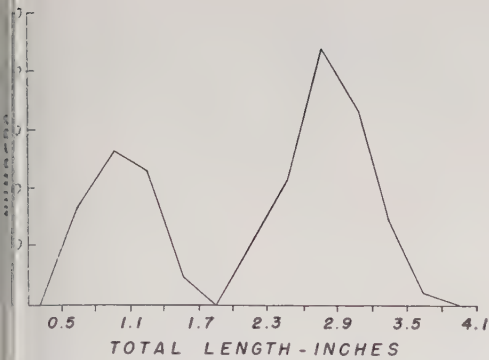


FIGURE 4.—Length frequency for 189 Utah chubs collected on August 6, 1953, from one location in Hebgen Lake, Montana.

mature males ranged in length from 5.8 to 10.5 inches with an average of 9.4. The 284 mature females varied in length from 7.4 to 12.5 inches with an average of 10.6, or more than 1 inch greater than the average males. The length-frequency distribution of the fish suggests one age group between 5.0 and 7.5 inches and another between 7.5 and 9.0 inches. Study of the scales shows that fish in the first size group were nearly all 3 years old and those in the second were 4 years old. Of the 160 fish in the first group 74.4 percent were immature, 25.0 percent were mature males, and 0.6 percent were mature females. In the second group of 182 fish, 29.1 percent were immatures, 57.1 percent mature males, and 13.8 percent mature females. No mature males less than 3 years were found, and no

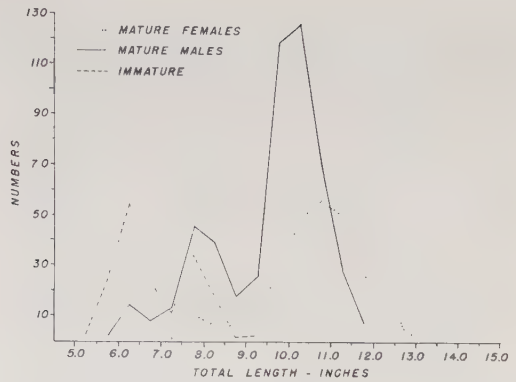


FIGURE 5.—Length frequencies for 524 mature male, 284 mature female, and 175 immature Utah chubs collected by gill nets during 1954 in Hebgen Lake, Montana.

mature females were younger than 4 years. Most of the measurements were made on fish caught in nets set in spawning areas just prior to the peak of the spawning activity (June 21–27). These nets took mostly males (age-groups V and VI) which accounts for the large mode at about 10.5 inches. A few chubs with undeveloped gonads were 5 years old. There is considerable overlap in age and size between immature and mature chubs, but males apparently mature a year sooner than females.

Scales of 475 Utah chubs (188 mature males, 183 mature females, 104 immatures) collected during 1953–54 were studied. These fish ranged in total length from 2.2 to 14.5

TABLE 4.—Average calculated total length (inches) of Utah chubs at succeeding annuli in Hebgen Lake, Montana—1953–54 collections

Age group	Sex	Number	Average total length at capture (inches)	Calculated length at each annulus							
				1	2	3	4	5	6	7	8
Immature.	I ¹	38	2.8	1.7	—	—	—	—	—	—	—
	I	2	4.5	1.4	3.1	—	—	—	—	—	—
	I	38	6.2	1.6	3.4	6.2	—	—	—	—	—
	M	15	6.2	1.6	3.7	6.2	—	—	—	—	—
	I	24	7.6	1.4	3.0	5.4	7.6	—	—	—	—
	M	22	7.7	1.6	3.4	5.7	7.7	—	—	—	—
	F	7	7.6	1.4	3.2	5.4	7.6	—	—	—	—
	I	2	8.2	1.3	2.4	4.1	6.4	8.2	—	—	—
	M	56	9.3	1.6	3.7	6.0	7.9	9.2	—	—	—
	F	44	9.7	1.6	3.9	6.1	8.0	9.6	—	—	—
	M	88	10.5	1.5	3.3	6.1	8.2	9.5	10.5	—	—
	F	101	11.0	1.6	3.7	6.3	8.4	9.9	10.9	—	—
	M	7	11.8	1.5	3.1	6.0	8.4	9.8	10.9	11.8	—
	F	27	12.5	1.6	3.4	6.5	8.9	10.4	11.5	12.4	—
	F	4	13.6	1.4	3.0	5.7	8.4	10.7	11.8	12.8	13.6
Adult.	I	104	—	1.6	3.4	5.9	7.5	8.2	—	—	—
	M	188	—	1.5	3.5	6.0	8.0	9.4	10.5	11.8	—
	F	183	—	1.6	3.7	6.3	8.4	9.9	11.1	12.5	13.6
	All	475	—	1.6	3.5	6.1	8.2	9.7	10.9	12.4	13.6

Immature.

inches and represented age-groups I to VIII. Scales were taken from the left side of the body between the lateral line and dorsal fin. Annuli beyond the fifth year were crowded and usually difficult to detect. Scale measurements were made along the antero-lateral radius. Calculated total lengths at each annulus were determined with a nomograph (Table 4), assuming a linear relationship between scale and body growth, since Neuhold (1955) found almost complete linearity in the body-scale relationship of the Utah chub.

The average calculated total length at each annulus was greater for females than for males and increased from 0.1 inch at annulus I to 0.7 inch at annulus VII. Because 27 females and 7 males in the sample were 7 years old, and 4 females and no males were 8 years old, it appears that females live longer than males.

The average calculated total length in inches of all chubs at the time of annulus formation at succeeding ages was I, 1.6; II, 3.5; III, 6.1; IV, 8.2; V, 9.7; VI, 10.9; VII, 12.4; VIII, 13.6. Hazzard (1935), who studied the growth of 26 Utah chubs from Fish Lake, Utah, calculated that total lengths in inches at the end of each year of life for the first 5 years were 1.3, 3.5, 5.5, 6.6, and 7.4 inches, respectively. The Fish Lake chubs were comparable in length at the second annulus with the Hebgen Lake specimens, but thereafter those from Hebgen Lake grew more rapidly. Neuhold (1955) reported that the weighted mean standard lengths of Utah chubs at the

end of succeeding years of life from I to VIII in Panguitch Lake were 1.3, 2.3, 3.6, 4.9, 6.3, 6.8, 7.3, 7.9, 8.6, and 8.8 inches, respectively, and in Navajo Lake were 1.6, 2.6, 5.4, 6.1, 6.7, 7.1, and 8.0 inches, respectively.

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Food Choice of Largemouth Bass as a Function of Availability and Vulnerability of Food Items¹

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ABSTRACT

Under experimental conditions largemouth bass (*Micropterus salmoides*) used golden shiners (*Notemigonus crysoleucas*) most heavily as food. Bluegills (*Lepomis macrochirus*) were used more heavily than green sunfish (*Lepomis cyanellus*). Green sunfish were chosen over bullheads (*Ictalurus melas*) and white crappies (*Pomoxis annularis*). Use of crayfish (*Orconectes immunis*) was variable, and in some cases they were not chosen at all. Natural-colored goldfish (*Carassius auratus*) were preferred over gold-colored ones. Green sunfish and bullfrog tadpoles (*Rana catesbeiana*) were eaten sparingly in comparison to golden shiners. The leopard frog tadpoles (*Rana pipiens*) were eaten commonly in one comparison with shiners but not at all in another trial. Small bullfrogs were utilized more intensively than shiners in one trial but not eaten in another trial. Utilization of small bullfrogs was variable when accompanied by crayfish; toads were not eaten when fed with leopard frogs. Food items thrown into the tank were usually taken instantly. During a period in the spring bass ceased feeding or fed very sparingly. The quantity of forage fish eaten daily amounted to 2.2 percent of body weight.

INTRODUCTION

The stomach contents of wild largemouth bass (*Micropterus salmoides*) have been the subject of many investigations (McLane, Dubets, 1954; Schneidermeyer and others, 1956). These food-habit studies have listed the foods commonly utilized by bass and have raised questions on the cause of selection of various food items. Whether food is chosen because it is more abundant, is more easily caught, or simply is preferred by the bass has remained a question. An additional complication is that the most desirable and most easily obtained foods are likely to be eaten first; thus many studies of stomach contents show feeding habits under conditions in which only less favored or less vulnerable food items are available. The present investigation was designed to study feeding habits when availability of food items was constant and when the items were made equally vulnerable as possible. The design of the study consisted of confining individual bass in tanks, feeding them an equal number of different food organisms, and observing which items were most readily taken. Even in feeding confined bass some difficulty is encountered in maintaining equal availability and producing equal vulnerability of food items. Availability of two food items

ceases to be equal when representatives of one item are eaten. The extreme situation exists when all of one particular food item is consumed. This difficulty was partly overcome by dividing feeding results into "eaten exclusively" and "eaten in combination" (Table 3). By confining food items with a bass in a tank without escape cover, the vulnerability of the food organisms was probably increased, but it may not have been made identical. Thus even in the confines of a tank some food organisms might be better able to escape capture than others.

METHODS

Wild bass varying in weight from 182 to 1,380 grams were placed in stock-watering tanks. If a bass was damaged or died, it was replaced by a new one from wild stock. Twenty-two bass were utilized in this study (Table 1). Even though four bass died from disease and five were killed by a faulty de-chlorination system, during the actual feeding experiments the bass appeared healthy and fed readily with the exception of a short period of time in the spring. The tanks measured 43 inches in diameter and contained 8 inches of water. They were equipped with overflows and each tank was flushed at the rate of 30 liters per hour. Water temperatures ranged from 74° to 80° F. With the exception of the development of an algal bloom on two occasions in two of the tanks, the water remained clear. The algal bloom

¹Study was financed by Southern Illinois University and the Illinois Department of Conservation.
²Present address: Department of Zoology, Tulane University, New Orleans, Louisiana.

TABLE 1.—Size, number of days used, and reason for discarding each bass employed in the study of food selection

Bass number	Total length (millimeters)	Weight (grams)	Number of days used	Reason for discarding
1	274	225	7	Acid kill ¹
2	290	308	7	Acid kill ¹
3	270	194	7	Acid kill ¹
4	298	294	7	Acid kill ¹
5	320	334	7	Acid kill ¹
6	303	316	14	Died (infection)
7	340	424	35	Became blind
8	295	332	88	Study finished
9	260	208	63	Died (infection)
10	245	182	4	Died (infection)
11	270	229	82	Study finished
12	253	188	56	Died (infection)
13	307	389	53	Study finished
14	320	427	18	Study finished
15	420	1,336	18	Study finished
16	375	1,150	15	Study finished
17	375	1,380	15	Study finished
18	307	646	42	Study finished
19	256	380	42	Study finished
20	329	598	8	Study finished
21	243	312	16	Study finished
22	354	1,127	25	Study finished

¹ From Na₂SO₃.

was eliminated by increasing the rate of flushing for a short period of time.

The bass were fed various combinations of the following food items: crayfish, *Orconectes immunis*; young bullfrogs, *Rana catesbeiana*; bullfrog tadpoles; leopard frogs, *Rana pipiens*; leopard frog tadpoles; Fowler's toads, *Bufo woodhousei fowleri*; golden shiners, *Notemigonus crysoleucas*; green sunfish, *Lepomis cyanellus*; bluegills, *Lepomis macrochirus*; white crappies, *Pomoxis annularis*; black bullheads, *Ictalurus melas*; natural-colored goldfish and gold-colored goldfish, *Carassius auratus*.

The choice of food items to be used for comparisons was based on their importance as a natural food and as bait. The two colors of goldfish were compared to determine if color might be important in food selection by the bass. Each experiment was begun by adding a complement of food, for example three golden shiners and three crayfish, to one of the tanks containing a single bass. After 24 hours had elapsed a record was made of the food items eaten or killed, and these items were replaced. After a period of several days preferences shown by the bass for the different food items could be determined. Three representatives of each food item were fed except on trials 5 and 23, in which six of each item were fed.

The different food items were matched, as near as practical, on the basis of length (Table 2). Since there was less choice of size

TABLE 2.—Lengths and weights of food organisms fed to largemouth black bass in determining preference

[Range of measurements in parentheses]

Food organism	Mean length ¹ (millimeters)	Mean weight (grams)
Crayfish	61 (56-69)	5.0 (3-12)
Bullfrog tadpole	125 (115-134)	17.0 (12-20)
Bullfrog	49 (42-51)	8.0 (6-10)
Leopard frog tadpole	58 (45-65)	3.0 (2-4)
Leopard frog	61 (55-66)	16.0 (10-20)
Toad	52 (45-68)	15.0 (8-20)
Goldfish	68 (56-70)	4.6 (3-6)
Golden shiner	79 (71-102)	4.0 (3-5)
Bullhead	69 (48-71)	5.5 (2-8)
Green sunfish	57 (46-66)	3.6 (2-5)
White crappie	71 (69-74)	3.0 (4-5)
Bluegill	54 (48-64)	3.0 (2-5)

¹ Crayfish, tip of rostrum to tip of telson; tadpoles, tip of snout to tip of tail; frogs and toads, tip of nose to tip of cloacal opening; fish, tip of snout to tip of caudal fin.

available in frogs, tadpoles, crayfish, and toads, fishes were selected that were approximately equal to these in length. Young bullfrogs were utilized in preference to adult frogs since they more nearly equaled the size of other food items.

Even though only an initial body weight of the bass is available, the amount of average food eaten daily by each bass is reported in terms of percentage of the bass' body weight. These values are taken to indicate the amount of food a bass will eat when the food is essentially unlimited and easily captured. The food supply was limited on 7 days when the food present was eaten. In addition, the amount eaten may have been different if the preferred food item had been continually available in unlimited supply.

RESULTS AND CONCLUSIONS

A number of generalities concerning food selection of the largemouth bass can be made possible by the data contained in Table 3. Golden shiners were eaten more readily than any other item fed. In some cases they were utilized exclusively, and in most trials they were utilized at more than twice the frequency of other forms. In only one trial did the bass utilize another food (small bullfrog) more intensively than shiners. Although in one trial only, the bluegill was more heavily utilized than the green sunfish, which in turn was chosen over bullheads and white crappie. The utilization of crayfish was quite variable. In some trials they were not utilized at all, while in two trials they were preferred to bullfrog tadpoles. Natural-colored goldfish were preferred over gold-colored goldfish. Goldfish of both colors made up a third

Fig. 3.—Food items offered compared with items eaten by confined largemouth bass

Food item ¹	Num- ber of bass fed	Num- ber of days fed	Oppor- tunities ²	Eaten exclu- sively	Eaten in combi- nation ³
Golden shiner	5	7	105	28	7
Green sunfish			105	4	6
Golden shiner	3	7	66	10	18
Green sunfish			66	8	16
Bluegill	5	7	105	9	32
Green sunfish			105	3	25
Green sunfish	5	7	105	22	2
Black bullhead			105	4	2
Black bullhead	5	7	210	18	—
Golden shiner	5	7	105	24	7
White crappie			105	1	5
Green sunfish	5	7	105	12	1
White crappie			105	4	1
Goldfish (natural)	5	7	105	8	13
Goldfish (gold)			105	6	9
Goldfish (natural)	5	7	105	18	4
Goldfish (gold)			105	3	5
Golden shiner	5	7	105	46	3
Goldfish (mixed)			105	2	1
Golden shiner	5	7	105	19	11
Goldfish (mixed)			105	7	9
White crappie	5	7	105	15	1
Goldfish (mixed)			105	14	1
Golden shiner	3	7	63	29	1
Crayfish			63	0	1
Bullfrog tadpole			63	0	2
Crayfish	7	3	63	15	13
Bullfrog tadpole			63	8	15
Crayfish	7	4	168	21	47
Bullfrog tadpole			168	1	24
Bullfrog tadpole	2	5	30	7	0
Crayfish			30	0	0
Golden shiner	5	3	45	5	18
Crayfish			45	1	10
Golden shiner	1	8	24	24	0
Crayfish			24	0	0
Golden shiner	7	3	63	22	17
Leopard frog			63	4	14
Golden shiner	1	9	27	15	0
Leopard frog			27	0	0
Small bullfrog	7	3	63	10	27
Golden shiner			63	3	25
Golden shiner	1	7	21	19	0
Small bullfrog			21	0	0
Crayfish	7	2	84	4	12
Small bullfrog			84	3	12
Small bullfrog	1	7	21	7	0
Crayfish			21	0	0
Golden shiner	1	11	66	29	15
Leopard frog tadpole			66	0	11
Leopard frog tadpole	1	7	21	19	0
Crayfish			21	0	0
Small bullfrog	1	18	39	5	1
Leopard frog			39	2	1
Leopard frog	1	10	30	2	0
Fowler's toad			30	0	0

¹Complement of three of each item except trials 5 and 6 where six of each item were fed.
²Opportunities equals number of bass fed times number of each food item offered in a 24-hour period times number of days feeding was done.
³Includes some 24-hour periods in which some bass ate both food items offered, thus reducing the probability of showing preference.

food taken in one trial with shiners, but a small portion in another trial. Bullheads were utilized only to a limited extent in comparison to green sunfish, but were utilized more heavily by larger bass than by smaller

ones. The green sunfish and bullfrog tadpoles were eaten sparingly in comparison to golden shiners, but up to 50 percent as well as crayfish, and on one trial they were eaten in preference to crayfish. Leopard frog tadpoles were eaten fairly well in comparison to golden shiners, and exclusively in comparison to crayfish. In comparison to shiners the leopard frog adult was utilized relatively well in one trial but not at all in another. The utilization of small bullfrogs was also variable. In one trial bullfrogs were utilized more intensively than shiners, but in another they were not eaten at all. The results were similar when bullfrogs were fed at the same time as crayfish. Bass appeared to have some difficulty in swallowing bullheads since they often grasped the bullheads but would frequently spit them out. Toads were not taken when fed together with leopard frogs.

The feeding records for individual bass were reviewed to determine if there was a detectable difference in the feeding of individual specimens, as compared with groups of bass, and whether any correlations with size of the bass existed. In a few instances the food utilized by an individual bass was not the same as that utilized by other bass that were simultaneously being fed the same food items. In two instances this difference in food utilized was associated with the size of the bass. Thus, when green sunfish and bullheads were offered together, the three smaller bass ate no bullheads, but the two large ones ate an equal number of both items. When goldfish and golden shiners were offered at the same time, the largest bass fed most heavily on goldfish. The smaller bass used golden shiners to a greater extent, but they ate some goldfish. In another trial when white crappie and bullheads were fed to bass at the same time, the larger bass utilized the white crappie to a greater extent.

Observations on feeding behavior indicated that the larger bass had greater difficulty in catching the shiners than in catching other food items. On the other hand, the constant movement on the part of the shiners appeared to attract the bass and may account for the shiner appearing as the preferred food. Another item of interest was the behavior of the bass when food was thrown into the tanks. Sometimes a tank contained a particular food item for several hours without its being eaten. When a specimen of the same item was thrown into the tank, however, it was usually taken at the instant it hit the water. This

TABLE 4.—Amount of food eaten daily by 22 captive bass fed in excess

Code number of bass	Initial weight of bass	Number of days fed	Food eaten	
			Grams	Percentage of body weight
1	225	7	18	1.2
2	308	7	46	2.1
3	194	7	83	6.1
4	294	7	9	0.4
5	334	7	5	0.2
6	316	14	11	0.2
7	424	35	194	1.3
8	332	88	664	2.3
9	208	63	250	1.9
10	182	4	23	3.7
11	229	88	506	2.5
12	188	56	251	2.4
13	389	53	294	1.4
14	427	18	633	8.2
15	1,386	18	194	0.8
16	1,150	15	356	2.1
17	1,380	15	623	3.0
18	646	42	361	1.3
19	380	42	476	3.0
20	598	8	95	2.0
21	312	16	111	2.2
22	1,127	25	119	0.4

behavior indicates a feeding response associated with the food suddenly hitting the water.

Cessation of feeding for approximately 2 weeks in the spring appeared to be associated with a stage in sexual development. During this period some of the bass fanned the bottom of the tanks in a manner suggestive of nest building. Tarrant³ observed cessation and resumption of feeding by a bass that was

³ Tarrant, Robert M. (1959) Sizes of forage fish preferred by largemouth bass (*Micropterus salmoides*) under aquarium conditions. M.S. Thesis, Southern Illinois University, Carbondale, Illinois. 21 pp.

found to be gravid a short time later. Brown (1946) found the appetite of brown trout (*Salmo trutta*) to be affected by the development of the gonads.

During the course of the study 982 items were eaten and 365 were killed but not eaten. There was no constant relation between the number of fish killed and number eaten. In a few cases the number killed exceeded the number eaten but in general the number killed was about one-third the number eaten.

The average amount of forage consumed daily by each bass was 2.2 percent of body weight. Some of the shorter feeding periods produced erratic values (Table 4).

ACKNOWLEDGMENTS

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Restoration of Anadromous Alewives at Long Pond, Maine

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ABSTRACT

From 1950 through 1953, 1,403 to 1,793 near-ripe anadromous alewives, *Alosa pseudoharengus*, were stocked annually at Long Pond, Hancock County, Maine, to restore an alewife run in the Long Pond drainage. The four stockings produced alewife runs of approximately 11,000 to 51,000 fish in a 3- to 5-year period following each stocking. Later runs (1958-59) produced by progeny of stocked fish were similar to those produced by stocking. There was little relationship between escapement and numbers of progeny 3 to 5 years later. Runs were of age-groups III-VIII but were dominated by age-groups IV-VI. Age-group III appeared in two of the six annual runs and in only one run in significant numbers. Fish of the large 1951 year class appeared in all runs from 1954 through 1959. Older alewives migrated early, but males and females migrated in about equal proportion throughout the run. Body and scale growth was essentially isometric above a body length of about 3.0 inches. Female alewives were significantly larger than males in the Long Pond drainage at ages IV, V, and VI. Fish of given age groups did not fluctuate significantly in size from year to year. Ultimate attainable lengths of male and female alewives determined by the method of Walford were 13.1 and 14.0 inches respectively. The observed sex ratio was 1.28 males to 1.00 female. Sixty-six and one-half percent of age-group V in the run had spawned once and 63.4 percent of age-group VI, twice. No fish of age-group III but all of age-group VI had spawned previously. Annual mortalities from age-groups V to VI and from VI to VII were calculated as 78.6 and 74.4 percent, respectively. The post-spawning mortality in Long Pond was 41 percent for age groups combined.

INTRODUCTION

Communities along the Maine coast are becoming increasingly interested in establishing commercial fisheries for the anadromous alewife, *Alosa pseudoharengus*. Well-managed alewife fisheries have often provided over \$2 profit per surface acre of lake spawning nursery area. Adult alewives are captured on their way to fresh-water spawning areas and processed to fishmeal or for human consumption. Decline of alewives in many Maine drainages occurred when obstructions were placed that prevented adults from reaching suitable lake spawning areas. In recent years removal of obstructions in Maine rivers have raised the possibility that many runs could be restored by construction of one or two intensive fishways or removal of defunct

damages. Gelow and Schroeder (1953) cite several drainages where runs were re-established by stocking adult alewives. Rounsefell and Hager (1943) carried out a vigorous restoration program in 1943 when 13 Maine waters were stocked with ripe fish. Where runs have been obliterated or reduced to a few annual stockings, stocking of ripe adults following restoration of fishways should aid restoration. The purposes of the present study were to develop the development of an alewife population following provision of fishways and removal of adult fish and to obtain informa-

tion about the life history of this species in Maine waters.

STUDY AREA AND HISTORY

A general description of the Long Pond drainage (Figure 1) is given by Havey (1960). The history of alewife runs in the Long Pond drainage is very similar to that of many other small drainages in Maine. During the 18th century alewives were reported to have frequented Long and Somes Ponds in large numbers. With the rise of the lumbering industry in the 19th century, dams were constructed that blocked access to upstream-lake spawning areas. Subsequently runs diminished to negligible numbers. In the Long Pond drainage, runs did not entirely disappear, because a few adults were usually caught below and released above the dams by citizens interested in preserving an alewife run.

Four low-head dams remained in the Long Pond drainage by 1950 (Figure 1). First Dam had the skeleton of a fishway built in the early 1930's when this dam was modified. Second and Third Dams were provided with satisfactory fishways. Fourth Dam had no fishway. Interested citizens of the area provided funds to complete fishways in both First and Fourth Dams in 1951.

PROCEDURES

From 1,403 to 1,793 adult alewives were stocked in Long Pond each year from 1950

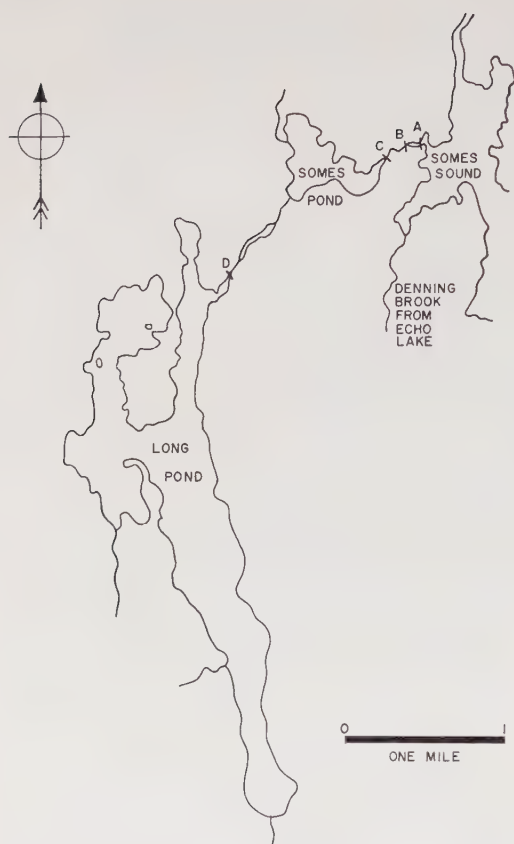


FIGURE 1.—The Long Pond drainage. A, B, C, and D are First, Second, Third, and Fourth Dams.

through 1953. These fish were captured on spawning runs in the Orland River, Hancock County, and transported to Long Pond, a distance of about 30 miles, by truck. Little mortality occurred when 200 to 300 fish were hauled at temperatures of 45° F. to 60° F. Cursory sampling confirmed the presence of males and females among the stocked fish.

All alewives that entered the Long Pond drainage between 1954 and 1959 were counted. The start of the spawning run was always detected by a two-way trap that was routinely operated in First Dam fishway for several weeks before the run began. Counts were made during the daylight hours on each day of the run as alewives passed through the exit of First Dam fishway. Attempts to count at night with various lighting arrangements were unsuccessful, so the counting station was closed each night with a hardware-cloth screen to prevent undetected movement.

Samples of alewives were taken almost daily

for determinations of length, sex, weight, age in 1954, 1957, 1958, and 1959 (Table 1). In 1955 and 1956 periodic samples were taken to coincide with appearance of schools of alewives judged to be fresh from the ocean. Fish were dipped from the fishway at approximately noon and processed the same day. Lengths were recorded to the nearest 0.1 inch and weights to the nearest 0.25 ounce. Sex was determined by dissection. Scales were taken from the left side of the fish at a point about midway between the origin of the dorsal fin and the lateral line.

The counts were subject to several major sources of error. Spent alewives began spawning back to sea before the incoming run was complete. Random movement of spent alewives back and forth over the counting weir was noted several times. Spent fish could usually be recognized, however, by their color, spawning condition, or both, and not included in the tally of upstream migrants. Beginning in 1958, a spent-fish bypass was constructed which largely eliminated this source of error.

Occasionally, incoming fish moved over the counting weir in such large numbers that precise tallying was difficult. These heavy runs were always of brief duration, however, and counts at such times are believed to have been accurate to within 5 percent of the actual numbers. On nearly every tide a few alewives died when trapped in rocks below or above the fishway entrance, or when stranded below the ebb tide. These fish were counted whenever possible and added to the total tally. Protection by herring gulls in tidal waters below the fishway was not a direct counting error, but did prevent, along with natural mortality, stranding below the fishway, a complete enumeration of the run. No estimate of the number of live alewives captured and eaten was possible. Another possible source of error in estimating the size of the runs was associated with commercial fishing in tidal waters below the Dam in 1956. The alewives taken in the fishery, however, were tallied by the bushel, and the number of bushels expanded to number of fish.

COUNTS AND AGE-GROUP COMPOSITION

A few alewives entered the Long Pond drainage in 1953, but no counts were made. These fish may have been progeny of the stocking that had matured at age III, or spawned from one of the original stocks of Orland River fish, remnants of the original Long Pond run, or possibly a mixture of alewives from these various sources. Com-

TABLE 1.—Number of alewives in various age groups that entered the Long Pond drainage from 1954 to 1959

Year	Number counted	Number sampled	Age group ¹					
			III	IV	V	VI	VII	VIII
1954	18,750	263	4,277	14,258	142	73	—	—
1955	60,606	119	1,018	47,873	11,715	—	—	—
1956	25,000	120	—	12,292	11,043	1,665	—	—
1957	33,080	212	—	22,627	7,959	2,494	—	—
1958	29,878	269	—	12,330	14,105	3,001	442	—
1959	40,810	220	—	29,926	8,126	1,661	735	362

¹January 1 annulus assumed for all age groups.

Results and data on age-group composition of the runs of 1954 through 1959 in the Long Pond drainage are summarized in Table 1.

Alewife runs usually began in early to mid-June at stream temperatures between 50° F. to 60° F. The earliest capture at First Dam was on April 26, 1958. Runs were over by June 15 in all years.

That progeny of fish stocked in 1950 contributed substantially to the run in the Long Pond drainage is clear from the abrupt increase in age-group V from 1954 to 1955 (Table 1). The few age-V and VI fish in the 1954 run were probably remnants of the original run or stocked fish which were spawned for the second or third time. No clear explanation can be given for the relatively low numbers of age-III fish in the 1954 run or the subsequent scarcity or lack of this age group. Alewives of the 1951 year class, which were abundant as age-group III in 1954 and age-group IV in 1955, appeared in every run from 1954 to 1959. Ages represented in the developing Long Pond alewife run are the same as those represented in other Maine rivers with long-established alewife runs.

Assuming that alewives produced in the Long Pond drainage returned to that drainage to spawn, there appears to be little relationship between escapement to the spawning areas

and subsequent production among alewives here (Table 2). It was expected that the 1958 and 1959 runs would be substantially larger than those of 1954–57, since escapement in 1954 and 1955 was many times greater than numbers of fish planted in 1950–53. Rounsefell and Everhart (1953) point out that, among prolific species of fish, it has seldom been possible to show a connection between numbers of spawners and number of progeny. Talbot (1954), however, showed that about 85 percent of the variation in size of the run of shad, *Alosa sapidissima*, in the Hudson River could be attributed to the escapement from the fishery. As the Long Pond drainage alewife run becomes more firmly established, a long-term correlation between number of spawners and numbers of progeny may become apparent.

To test whether alewives of different age groups or of different sex predominated at certain periods in the runs, all fish sampled in 1957–59 were divided into three groups based on periods of the run when they were taken. These periods were first third of run, middle third of run, and last third of run. The numbers of each age and each sex (age groups combined) in each time period were then compared with expected frequencies (one-third in each time division) by the chi-square test.

TABLE 2.—Relationship between escapement and size of subsequent alewife runs in the Long Pond drainage

[Numbers in thousands]

Escapement year ¹	Escapement (number) ²	Numbers in subsequent years ³						Total
		1954	1955	1956	1957	1958	1959	
1950	1.5	14	4	—	—	—	—	18
1951	1.5	4	44	3	—	—	—	51
1952	1.5	—	1	9	1	—	—	11
1953	2	—	—	—	22	5	—	27
1954	17	—	—	—	—	11	2	13
1955	57	—	—	—	—	—	29	29 ⁴

¹Values for the years 1950–53 are stocked fish as in text.

²Estimated to nearest 500.

³Includes only alewives spawning for the first time.

⁴Production figures not complete for escapement year 1955, since some alewives produced in that year will spawn the first time in 1960.

TABLE 3.—*Distribution of alewives of different ages and sexes by time periods in the 1957-59 runs*

Time division	Number by age group			Number by sex	
	IV	V	VI and VII	Male	Female
First third of run	129	81	32	149	107
Middle third of run	144	70	18	139	116
Last third of run	142	71	10	144	99
Chi-square (2 d.f.)	1.23	1.00	9.42	0.34	1.34

Age-groups VI and VII were combined because of their relatively poor representation.

The chi-square value for age-groups VI and VII (Table 3) is significant at the 99-percent confidence level. Values for age-groups IV and V and for the sexes are not significant if 95 percent is accepted as a satisfactory level of confidence. Apparently older alewives run early.

GROWTH

Body length-scale length ratios of alewives in the Long Pond drainage changed little between lengths of 3.0 and 13.0 inches (Table 4). At lengths less than 3.0 inches, scales grew more rapidly than the fish.

The body-scale regression (scale length, Y , on body length, X) for 264 fish over 3.0 inches was described most satisfactorily by a straight line that passed virtually through the origin ($Y = 0.038 + 0.42870X$). Direct proportion was therefore used to back-calculate lengths at various ages. Calculated lengths so derived (Table 5) agreed well with empirical lengths at ages at which comparisons could be made.

Size of alewives of a given age and sex fluctuated little from year to year. For example, age-IV males averaged from 11.5 ± 0.05 to 11.7 ± 0.10 inches, total length, in the 6 years 1954 through 1959. Age-V females averaged 12.4 ± 0.10 inches in 1955, 1956, and 1957 and 12.5 ± 0.10 inches in 1958. Since these fish were drawn from year classes that ranged in abundance from 11,000 to 51,000 at maturity (Table 2), it does not appear that the size of the year class affects total length attained at these levels of abundance. MacGregor (1959), who worked with sardines, *Sardinops caerulea*, demonstrated a high inverse correlation between population size and fish length but felt that the correlation was primarily a parallel one associated with entrance of large year classes into the population and not a cause-and-effect correlation.

TABLE 4.—*Body length-scale length ratios in alewives*

Length group (inches)	Number of fish	Mean body length (inches)	Mean scale radius ¹ (inches)	R
1.1- 1.5	18	1.3	0.26	
1.6- 2.0	20	1.8	0.48	
2.1- 2.5	18	2.3	0.67	
2.6- 3.0	12	2.8	0.86	
3.1- 3.5	12	3.3	1.40	
10.1-11.0	48	10.9	4.80	
11.1-12.0	190	11.6	5.10	
12.1-13.0	169	12.6	5.34	

¹ Scale lengths (anterior radii) are $\times 22$. Samples of adults were drawn from all the study years. Samples of juvenile alewives were drawn from the 1954 and 1955 year classes.

² Mean body length divided by mean scale radius $\times 100$.

Beyond age III, female alewives of the Long Pond drainage grew more rapidly than males (Table 6). The values of t are significant at the 95-percent confidence level for age-V females and at the 99-percent level for age-IV and age-V males. Possibly the slower growth of the male alewife results from its earlier maturation.

Ultimate attainable lengths for male and female alewives determined by the method of Walford (1946) were 13.1 and 14.0 inches, respectively. Only 2 of 674 males sampled exceeded the ultimate attainable length so derived. No females exceeded 14.0 inches, although this ultimate length refers specifically to alewives of the Long Pond drainage, and 188 fish sampled from other Maine rivers exceeded three males and one female exceeded the ultimate lengths determined for Long Pond fish.

SEX RATIOS

Of 1,194 alewives examined for sex between 1954 and 1959, 674 or 56.4 percent were males. For age-groups III, IV, V, and VI, respectively, 75.8 (47 of 62), 55.3 (427 of 771), 55.1 (168 of 305), and 57.1 (32 of 56) percent were males. Chi-square tests revealed that for all samples combined, the observed deviation from a hypothesized 1:1 ratio could

TABLE 5.—*Calculated total length (inches) of alewives in Long Pond drainage collected during the years 1954-59*

Sex	Age				R
	I	II	III	IV	
Male	5.2 (74)	8.7 (74)	10.7 (63)	11.8 (30)	1
Female	5.3 (70)	8.7 (70)	10.8 (64)	12.0 (31)	1
All fish	5.3 (144)	8.7 (144)	10.8 (127)	11.9 (61)	1

[Number of fish in parentheses]

TABLE 6.—*Test of t comparisons between empirical total lengths (inches) of male and female alewives of ages IV–VI, 1957–59*

Age	Number in sample		Mean total length (inches)		Standard error of difference	d.f.	t
	Male	Female	Male	Female			
I	30	30	11.63 ± .06	12.00 ± .06	.0912	58	4.16
	30	30	12.14 ± .08	12.41 ± .06	.1053	58	2.56
	20	20	12.39 ± .09	12.92 ± .09	.1350	38	3.92

arisen by chance only 1 in 100 times. The relatively large percentage of males in group III indicates that they mature and spawn before females. For the individual groups, ages III, IV, and V had more males than 99-percent, 95-percent, and 90-percent confidence levels, respectively. At age VI the expected difference could have arisen from chance one in two times.

REPEAT SPAWNING

As with other Clupeidae (Bigelow and Schroeder, 1953; Cating, 1953), alewives spawn in several consecutive years. The percentages of repeat spawning for Long Pond (Table 7) are minimum values, since some alewives may not remain in fresh water sufficiently long for scale absorption (the guide to spawning-check interpretation) to be pronounced. Apparently some alewives matured at age III and all were mature at age V. No age VI fish were examined which had not spawned previously. It will be noted that a small percentage of age-IV fish in the 1957–59 samples were judged to have spawned previously; yet no age-III fish were taken in samples of runs of 1956–59 (Table 1). Spawning checks on age-III fish are not as pronounced on older fish, and there may not even be records of spawning but rather a false check caused by unknown factors.

MORTALITY

Annual expected mortality of alewives from age V to age VI and from age VI to age VII

TABLE 7.—*Spawning history of 701 alewives in the 1957–59 samples and 60 age-III fish of the 1954 sample*

	Percentage of fish that had spawned			
	0 times	1 time	2 times	3 times
100.0	0.0	0.0	0.0	0.0
96.7	3.3	0.0	0.0	0.0
30.7	66.5	2.8	0.0	0.0
0.0	36.6	63.4	0.0	0.0
0.0	12.5	50.0	37.5	0.0
0.0	0.0	0.0	100.0	0.0

was 78.6 and 74.7 percent respectively, based on numbers of fish of different ages in the runs (Table 1). Mortalities from age IV to age V could not be validly determined from the data because some alewives do not spawn for the first time until age V. Because the sample is larger and ages of V- and VI-group fish are more easily determined, the expected mortality for age V to VI (78.6 percent) is undoubtedly the more reliable.

An accurate assessment of the mortality which occurs soon after spawning in Long Pond, the uppermost pond in the drainage, is possible through analysis of up- and downstream trap captures of alewives at the Fourth Dam trap (Figure 1). Between 1954 and 1959, 10,113 ripe alewives were trapped and released over Fourth Dam. During this same period 5,997 spent fish were trapped and released downstream. Annual mortalities for the 6-year period ranged from 32 to 67 percent and averaged 41 percent. These figures may not be representative of the post-spawning, fresh-water mortality of the run as a whole because several hazards to downstream migration exist in the stream between Long Pond and the sea. The average for all years (41 percent), however, is considered a good estimate of percentage of post-spawning mortality in the ponded areas of the drainage.

MANAGEMENT IMPLICATION

The present study has clearly shown that alewife runs can be restored in a relatively short time by providing access to lake spawning areas and then stocking adult spawners. The initial plantings at Long Pond were sufficient to establish what appeared to be near maximum runs for this particular drainage (Table 1). Establishment could probably be effected by only one or two plantings, since the fish mature at different ages and repeat spawning is common.

Predictions concerning degree of utilization of a drainage by alewives where the connecting streams between the lake nursery and spawning areas are small should be made with

care. In the Long Pond drainage only 10,113 of over 200,000 alewives that entered the drainage between 1954 and 1959 continued through Somes Pond (Figure 1) and up into Long Pond, the major spawning and nursery area in the drainage.

At the present time Maine regulations provide a 24-hour "closed" period on alewives each week during the spawning runs to insure adequate escapement. Towns controlling fisheries, however, may close their rivers for additional periods. The present study indicates that the weekly 24-hour closed period is adequate to insure sufficient escapement. If future counts at Long Pond continue to indicate little relationship between escapement and subsequent production, towns now restricting their fisheries to 3 or 4 days a week might find it desirable to liberalize their fishing regulations to permit fuller utilization of this resource.

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Some Effects of Rotenone Products on Municipal Water Supplies¹

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ABSTRACT

Five coves of Lake Lavon and a small lake in north-central Texas were treated with five different rotenone products. Of 18 water tests made before, during, and after treatments, four showed significant change. Turbidity decreased and plankton and bacterial counts increased. The most important change was in taste and odor of treated waters. Rotenone products, such as Noxfish, Chem Fish Regular HFN, and Chem Fish Special HFN, produce undesirable tastes and odors in water. A temporary taste and odor from decomposition of the fish killed can also be expected after treatment. Laboratory tests showed these conditions can be controlled with 1.0 p.p.m. of activated carbon for each threshold odor number produced. Rotenone treatments may cost water plants an additional \$60 to \$95 per million gallons of water produced during the first few days after application. Rotenone powder and Chem Fish Synergized HFN were the first and second choices for municipal waters because taste and odor problems are reduced and costs are lower. Spring and fall were found the best seasons for municipal lake treatments in Texas.

INTRODUCTION

During the past few years the use of various chemicals has become a standard tool in fish-management. Some are used to control aquatic plants, others to reduce turbidity, and others to increase the fertility. One group, the piscicides, are fish toxicants used to kill undesirable fish species or entire unwanted fish populations. Numerous lakes and streams in Texas have been treated with various toxicants, most of which contained rotenone, or a combination of rotenone-bearing ingredients (Strey, 1958; Jurgens, 1959; Bonn, 1959; Holbert, 1959; Lamb, 1960). In most cases the work has been limited to waters not used for human consumption because of the opinion that such treatment might result in contamination of the water with harmful, as well as taste- and odor-producing, organisms. Texas cities have assumed that the State Health Department would not disapprove their water supply and have requested the Texas Game and Fish Commission to treat their municipal water supplies. These cities have placed good fishing and recreational use of their lakes on a par with domestic, industrial, and commercial uses of their water.

This problem has also occurred in other states with the result that Massachusetts allows the Game and Fish Department to collect fish-population samples with rotenone in municipal reservoirs (Stroud, 1956). In California,

Hodges Reservoir, a water source for San Diego, was treated for a complete fish kill after certain precautions were agreed upon (Hoffman and Payette, 1956). From 1949 to 1953 almost 30 city lakes in Oklahoma were treated with rotenone for partial, selective, or complete eradication of fish (Eschmeyer, 1953). Here the cities were informed of the condition of the fish populations in their lakes and told the best method for correcting overabundant rough fish and overcrowded pan fish. In cases where rotenone was needed, it was used with the cooperation of the Public Health Department and city officials.

The Texas Game and Fish Commission, while respecting the opinions and policies of others, felt that some work should be done and data collected to prove or disprove the belief that various rotenone compounds could be safely used in potable water supplies. Reliable tests by the manufacturers of these chemicals² and others (Haag, 1931) show that rotenone compounds, in concentrations used for fish-management purposes, are not harmful to warm-blooded animals.

This study was planned to determine the indirect effects of rotenone products on municipal waters. Five coves in Lake Lavon and Bonham State Park Lake were treated with five different rotenone products by fisheries workers of the Texas Game and Fish Commission. Eighteen different water tests were

² Penick, S. B., and Co. (1959) An interim report on the toxicity of Pro-Noxfish. New York, N. Y. 32 pp. (multilithed).

¹ Contribution of Dingell-Johnson Project F-8-R, Texas Game and Fish Commission.

made in these areas and at three control stations, before, during, and after the application of the toxicants, by chemists of the North Texas Municipal Water District. The State Department of Health was interested in any physical, chemical, bacteriological, or biological changes which might influence city water supplies.

DESCRIPTION OF SITE AND SAMPLING AREAS

Lavon Reservoir was selected as the work site because it is close to the water district's laboratory (Figure 1) and because of past experience with and knowledge of the lake. Two major jobs^{3,4} and two later jobs^{5,6} on this body of water have been completed by the Game and Fish Commission's Inland Fisheries Division. The North Texas Municipal Water District has water-analysis records dating from June 1957, and in early 1958 three permanent sampling stations were established at Lavon.

This reservoir, located on the East Fork Trinity River in southern Collin County, Texas, was completed in 1953. The lake was built for flood control and has a total storage capacity of 423,400 acre-feet. Of this, 275,000 acre-feet is for flood storage, 100,000 acre-feet for conservation pool, and 47,800 acre-feet for sediment reserve. The 100,000 acre-feet of conservation storage has been allocated for domestic, municipal, and industrial use. Ten north Texas communities united their efforts and organized the North Texas Municipal Water District, an agency of the State of Texas, and utilized this volume for their water supply.

The three permanent sampling stations were used as control points to compare with conditions created in various coves and bays by the addition of rotenone products. One station is on each of the two main arms of the lake,

while the third is at the water intake to (Figure 1). The East Fork and Pilot water stations were each marked by the Corps of Engineers with a permanent floating buoy to locate them and to serve as a mooring for the boat while collecting water samples.

Five sites representative of the habitat at Lake Lavon were selected for chemical treatment (Figure 1). Clear Lake, a 3½-acre cove containing approximately 13 acre-feet of water, was the first area worked. Price Creek enters Lavon from the east in a wide, flat area which is almost separated from the main lake by a railroad fill. It is connected to the reservoir by a 120-foot-wide channel which is set at a cross angle to the normal wind directions. As a result the 32 acres in the cove are little affected by wind and wave action from the main lake. Baptist Bay and East Trinity Cove are both on the East Fork Trinity River of the lake. Baptist Bay is a 13-acre cove containing 46 acre-feet of water on the north shore. Almost directly across the lake, a 4-acre East Fork Cove measured only 10 acres. In December, Beverly Bay, a 6-acre cove containing 19 acre-feet of water and located on the Pilot Arm, was worked.

In late April, Bonham State Park Lake, a 49-acre impoundment in central Fannin County containing 360 acre-feet of water, was treated for a complete fish kill.⁷

METHODS

Before treatment each cove was blocked off with a 1-inch-mesh nylon net to prevent movement of fish into or out of the cove. Fish not affected by the chemical were collected, identified, sorted, counted, and bulk weighed by species. After their body cavities were punctured, these fish were put back into the water area to create as natural a condition following a treatment as possible. At Price Creek Baptist Bay, where the kills were extremely heavy, estimated numbers and pounds of fish were computed from proportional shore collections.

Treatment with rotenone products

Standard piscicides, including 5-percent rotenone powder and 5-percent rotenone emulsion (Noxfish), were used in three treatments. Realizing that odor from a methylene

³ Bonn, E. W., and C. R. Inman. (1954) Inventory of species present in Lavon Reservoir and its drainage in Collin County, Texas. Texas Game and Fish Comm., Federal Aid Compl. Rept. F-8-R-1, Job B-4, 12 pp. (multilithed).

⁴ Bonn, E. W., and C. R. Inman. (1955) Population study of Lavon Reservoir. Texas Game and Fish Comm., Federal Aid Compl. Rept. F-8-R-2, Job B-9, 16 pp. (multilithed).

⁵ Bonn, E. W. (1959) Resurvey of the major waters of Region 2-B. Texas Game and Fish Comm., Federal Aid Compl. Rept. F-8-R-5, Job B-16, 23 pp. (multilithed).

⁶ McClellan, W. G. (1958) Experimental introduction of white bass in Lakes Lone Star and Lavon. Texas Game and Fish Comm., Federal Aid Compl. Rept. F-8-R-4, Job F-2, 2 pp. (multilithed).

⁷ Bonn, E. W. (1959) Complete kill of fish in Bonham State Park Lake. Texas Game and Fish Comm., Federal Aid Compl. Rept. F-14-D-3, Job a-13, 7 pp. (multilithed).

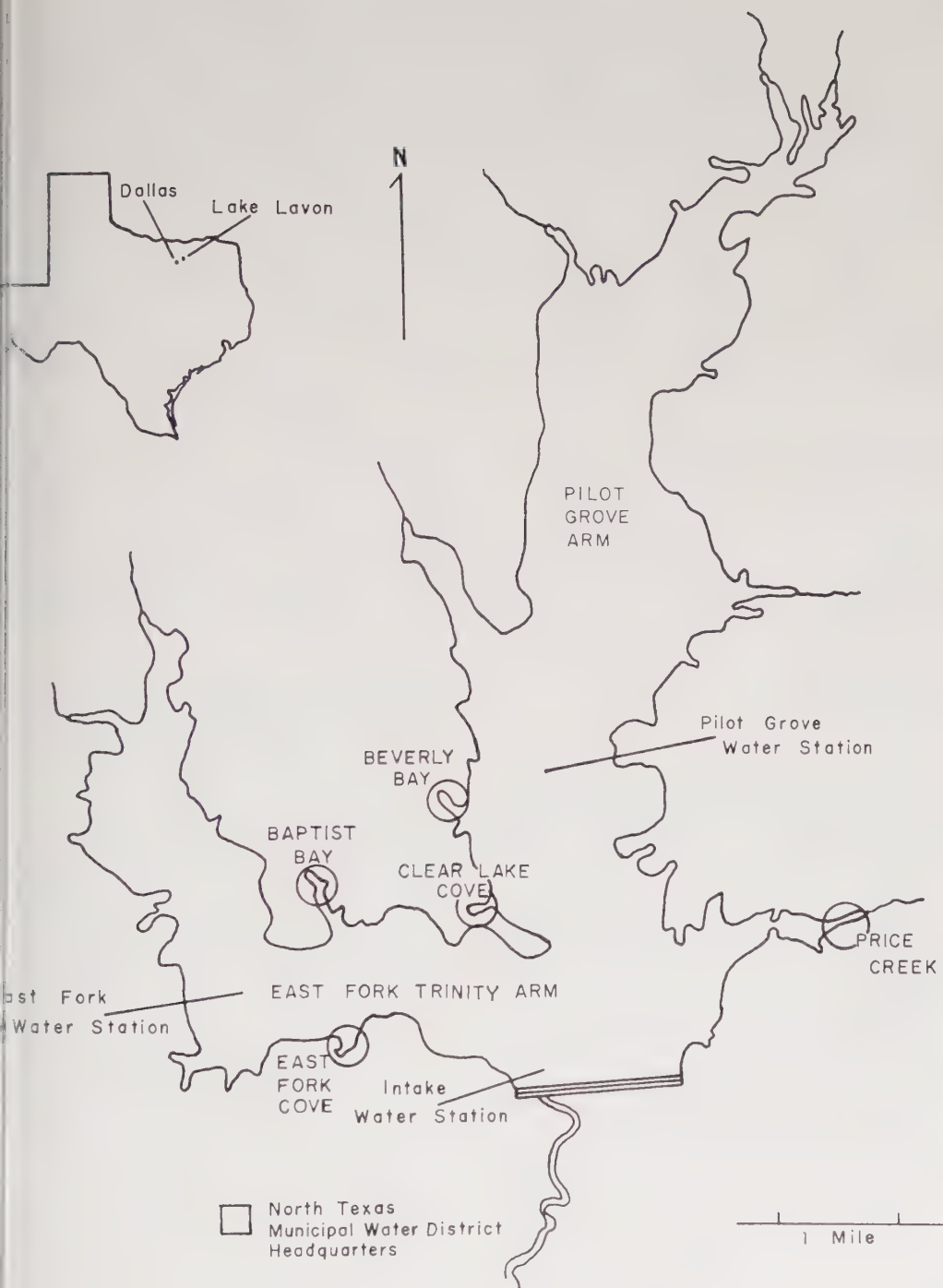


FIGURE 1.—Lake Lavon, showing permanent water stations and areas treated.

TABLE 1.—*Areas treated with fish toxicants, nature of treatment, and results*

Item	Clear Lake Cove	Bonham Park Lake	Price Creek	Baptist Bay	East Fork Cove	Beverly Bay
Location	Lavon Pilot Arm	Central Fannin County	Lavon Pilot Arm	Lavon Elm Arm	Lavon Elm Arm	Lavon Pilot Arm
Date	March 24	April 28	June 16	September 1	November 2	December
Area	3.4 acres	48.8 acres	31.75 acres	13.1 acres	3.97 acres	5.75 acres
Average depth	3.8 feet	7.39 feet	1.29 feet	3.5 feet	2.57 feet	3.35 feet
Maximum depth	10.0 feet	15.5 feet	9.0 feet	8.0 feet	6.5 feet	7.5 feet
Volume (acre-feet)	12.92	360.6	40.96	45.85	10.20	19.26
Rotenone product	Noxfish	Noxfish (0.82 p.p.m.) and 5 percent powder (0.41 p.p.m.)	5 percent powder	Chem Fish Regular HFN	Chem Fish Synergized HFN	Chem Fish Special HFN
Concentration	1.39 p.p.m.	1.23 p.p.m.	1.36 p.p.m.	0.65 p.p.m.	0.5 p.p.m.	1.53 p.p.m.
Type of kill attempted	Entire cove	Entire lake	Entire cove	Entire cove	Shad in cove	Entire cove
Application method	Handspray and propwash	Powerspray and propwash	Powerspray	Powerspray and propwash	Handspray and propwash	Propwash
Weight of fish killed	195 pounds	7,063 pounds	2,500 pounds	2,800 pounds	41 pounds	160 pounds
Weight of fish killed per acre-foot	15.09 pounds	19.58 pounds	61.04 pounds	61.07 pounds	4.02 pounds	8.31 pounds
Maximum odor number determined	5-kerosene	30-kerosene	30-fishy	10-fishy	7-fishy	7-kerosene
Air temperature	68° F.	72° F.	92° F.	80° F.	65° F.	75° F.
Water temperature	55° F.	70° F.	91° F.	84° F.	68° F.	50° F.
pH	8.2	8.2	8.3	8.4	8.4	8.3
Turbidity	34 p.p.m.	68 p.p.m.	84 p.p.m.	42 p.p.m.	40 p.p.m.	30 p.p.m.
Total alkalinity	123 p.p.m.	124 p.p.m.	126 p.p.m.	100 p.p.m.	109 p.p.m.	110 p.p.m.
Total hardness	136 p.p.m.	126 p.p.m.	134 p.p.m.	120 p.p.m.	120 p.p.m.	132 p.p.m.
Wind direction	SSE	N	SE	SE	S	SE
Wind velocity	14 m.p.h.	8 m.p.h.	3 m.p.h.	8 m.p.h.	3 m.p.h.	7 m.p.h.

naphthalene carrier for emulsified rotenone might be undesirable for some waters, the Chemical Insecticide Corporation prepared a product with a hydrocarbon-type carrier which had a lower boiling range and contained less odorous materials. This carrier, called HFN, is available in all of their emulsifiable rotenone products and was tried in three areas during the study (Table 1).

The first treatment of this study was made in March 1959, when Clear Lake Cove was treated with 1.39 p.p.m. of Noxfish. At Bonham State Park Lake 0.82 p.p.m. of Noxfish and 0.41 p.p.m. of 5-percent rotenone powder, or a total of 1.23 p.p.m. of rotenone products, were used. In mid-June 1.31 p.p.m. of 5-percent rotenone powder was sprayed on the waters of Price Creek. While the water was still warm in early September, Baptist Bay was treated with 0.65 p.p.m. of Chem Fish Regular with HFN carrier. A selective kill for shad was attempted in early November at East Fork Cove with Chem Fish Synergized HFN at the rate of 0.5 p.p.m. The final field test during 1959 was made when Beverly Bay was treated with 1.53 p.p.m. of Chem Fish Special HFN.

Sample collection and analysis

The normal level of Lake Lavon is 472 feet mean sea level, and while this varied less than

5 feet during the entire year, a surface sample was taken at all three stations. Another sample at all stations was taken at elevation 4 or 7 feet below the normal surface. At water intake station a third sample was taken at elevation 455, or 17 feet below the normal surface, and a fourth was collected near bottom at elevation 450. The lake is approximately 22 feet deep at this point. A near bottom sample was also taken from the stations with the East Fork sample collected from elevation 456, or 16 feet deep, and the Pilot Arm sample collected from elevation 458, or 14 feet deep.

Collection of these 10 samples at the three permanent stations at approximate 2-week intervals during the year resulted in a total of 180 analyses for 18 trips. The permanent station samples were collected at least once, and, on a few occasions, twice, while collection treatment work was being done. The 18 terminations on samples collected at the permanent water stations were also made. Samples taken from the treated coves at meter depths before, during, and several times after the application of the fish toxicants. Samples were collected daily until the taste and odor returned to normal. After that, samples were taken at irregular intervals for several months.

TABLE 2.—Analysis of water quality in Lavon Reservoir on April 15, 1959¹

[Chemical content expressed in parts per million; plankton in numbers per milliliter]

Item	Intake structure				East Fork Arm			Pilot Grove Arm		
	Surface 471.3	465	455	Bottom 450	Surface 471.3	465	Bottom 456	Surface 471.3	465	Bottom 458
Temperature (° C.)	14 8.4	14 8.4	14 8.35	13 8.3	14 8.4	14 8.4	14 8.4	14 8.4	14 8.4	14 8.35
Acidity	50	50	56	120	66	76	132	60	66	70
Dissolved oxygen	9.5	9.2	9.2	8.8	9.2	9.5	9.4	9.8	9.7	9.7
Carbon dioxide	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Alkalinity	132	130	130	130	128	130	132	130	130	130
Hardness	136	136	136	136	140	142	144	142	142	144
Calcium	46.4	46.4	46.4	46.4	47.0	47.8	48.4	47.8	47.8	48.4
Nitrogen	0.03	0.08	0.14	0.14	0.14	0.08	0.08	0.10	0.08	0.09
Ammoniacal nitrogen	0.21	0.30	0.22	0.23	0.21	0.20	0.26	0.22	0.22	0.20
Nitrogen	0.24	0.38	0.36	0.37	0.35	0.28	0.34	0.32	0.30	0.29
Chlorophyll	0.80	0.70	0.60	0.45	0.65	0.65	0.60	0.75	0.65	0.60
Plankton	tr. ²	tr.	tr.	tr.	tr.	tr.	tr.	tr.	tr.	tr.
Cystids	952	1,211	2,076	3,114	1,125	2,076	3,547	1,038	1,730	3,806
Amphipoda	314	470	470	706	314	392	666	392	392	706
Cladocera				39			118		39	78
Rotifera			78	39		39	78		39	39
Plankton	1,266	1,681	2,624	3,898	1,439	2,507	4,409	1,430	2,200	4,629
Number	4-mu. ³	5-mu.	5-mu.	5-mu.	5-mu.	5-mu.	5-mu.	5-mu.	5-mu.	5-mu.
Probable number	6	6	6	23	6	21	23	6	6	23
Number of bacterial colonies per milliliter	100	300	800	2,000	600	1,100	1,800	1,500	2,500	2,100

Air temperature, 60° F.; wind direction, south.

tr. = less than 0.01 p.p.m.

mu. = musty.

At Bonham State Park Lake water samples were collected at the surface, 5 feet deep, 10 feet deep, and 15 feet deep at the bottom and analyzed before, during, and after chemical treatment.

The determinations made on each water sample were selected because they were believed to be necessary to this study. Zooplankton identifications and counts were not made because it was believed that their influence on the treatment of municipal water is insignificant, and because the samples were concentrated and only rarely did the water permit chemist encounter a plankton animal in the 1-milliliter sample. An example of one of the water tests is shown in Table 2.

With the exception of the odor number test, determinations have been made by, or are at least familiar to, most fisheries biologists. The odor test is the accepted method of determining taste and odor in the waterworks industry and is approved and described by the American Water Works Association (American Public Health Association *et al.*, 1955).

RESULTS OF FIELD TESTS

During field tests wind and water currents had a major effect on both the success of fish kills and the results of the water analyses. The treatments for investigation were the experiments in Bonham Park Lake and Price

Creek, where wind and water currents were not a problem.

Effectiveness of treatment

Even though 15 pounds of fish per acre-foot were killed at Clear Lake Cove, check nets showed some of the fish remained alive inside the treated areas. A strong wind created currents that quickly moved the chemical out of the cove. A slick appearance on the water was noticed drifting north up the lake, and sick carp (*Cyprinus carpio*) were observed nearly 2 miles away 8 hours after application of the toxicant.

At Bonham Park the entire lake was treated with rotenone chemicals and almost 20 pounds of fish per acre-foot of water were killed. At no time during this study did the lake overflow, so dilution or dispersion were not problems, as experienced with the Lavon Cove applications. At Price Creek the wind was not strong and the cove is joined by a narrow connection to the main lake. An estimated 61 pounds per acre-foot, or 2,500 pounds of fish, were affected by this treatment.

While more than 60 pounds of fish per acre-foot were killed at Baptist Bay, test netting showed a few fish remained alive after the treatment. Large numbers of threadfin shad (*Dorosoma petenense*), which came through the 1-inch-mesh block net, were affected by

TABLE 3.—Species of fish in Lavon Reservoir and Bonham State Park Lake and their relative abundance

Species	Relative abundance ¹	
	Lavon	Bonham Park (before treatment)
Longnose gar (<i>Lepisosteus osseus</i>)	F	—
Shortnose gar (<i>Lepisosteus platostomus</i>)	C	—
Spotted gar (<i>Lepisosteus oculatus</i>)	C	—
Gizzard shad (<i>Dorosoma cepedianum</i>)	VA	VA
Threadfin shad (<i>Dorosoma petenense</i>)	VA	—
Smallmouth buffalo (<i>Ictiobus bubalus</i>)	F	R
River carpsucker (<i>Carpodius carpio</i>)	C	C
Spotted sucker (<i>Mineytrema melanops</i>)	R	—
Carp (<i>Cyprinus carpio</i>)	VA	C
Stoneroller (<i>Camptostoma anomalum</i>)	R	—
Bullhead minnow (<i>Pimephales vigilax</i>)	C	C
Fathead minnow (<i>Pimephales promelas</i>)	R	—
Golden shiner (<i>Notemigonus crysoleucas</i>)	F	C
Pugnose minnow (<i>Opsopoeodus emiliae</i>)	R	—
Red shiner (<i>Notropis lutrensis</i>)	A	A
Ghost shiner (<i>Notropis buchanani</i>)	R	—
Blacktail shiner (<i>Notropis venustus</i>)	R	R
Channel catfish (<i>Ictalurus punctatus</i>)	A	C
Black bullhead (<i>Ictalurus melas</i>)	C	R
Yellow bullhead (<i>Ictalurus natalis</i>)	C	—
Flathead catfish (<i>Pylodictus olivaris</i>)	R	—
Tadpole madtom (<i>Noturus gyrinus</i>)	C	—
American eel (<i>Anguilla rostrata</i>)	—	R
Blackstripe topminnow (<i>Fundulus notatus</i>)	C	C
Mosquitofish (<i>Gambusia affinis</i>)	C	F
Pirate perch (<i>Aphredoderus sayanus</i>)	R	—
Mississippi silverside (<i>Menidia audens</i>)	—	C
White bass (<i>Roccus chrysops</i>)	C	—
Largemouth bass (<i>Micropterus salmoides</i>)	F	A
Spotted bass (<i>Micropterus punctulatus</i>)	F	—
Warmouth (<i>Chaenobryttus gulosus</i>)	C	F
Green sunfish (<i>Lepomis cyanellus</i>)	F	F
Spotted sunfish (<i>Lepomis punctatus</i>)	F	—
Redear sunfish (<i>Lepomis microlophus</i>)	R	A
Bluegill (<i>Lepomis macrochirus</i>)	C	VA
Orangespotted sunfish (<i>Lepomis humilis</i>)	F	F
Longear sunfish (<i>Lepomis megalotis</i>)	F	C
White crappie (<i>Pomoxis annularis</i>)	VA	VA
Black crappie (<i>Pomoxis nigromaculatus</i>)	R	—
Logperch (<i>Percina caprodes</i>)	F	—
Slough darter (<i>Etheostoma gracile</i>)	R	—
Bluntnose darter (<i>Etheostoma chlorosomum</i>)	—	—
Dusky darter (<i>Percina sciera</i>)	R	—
Freshwater drum (<i>Aplodinotus grunniens</i>)	A	—
Total number of species recorded	42	22

¹ VA — very abundant; A — abundant; C — common; F — frequent; and R — rare.

the chemical and increased the kill for this sample.

The selective kill for shad at East Fork Cove was successful even though only 4 pounds of fish per acre-foot of water were removed. The treatment was selective since 94.7 percent of the fish observed and 89.6 percent of the total weight was made up of threadfin and gizzard shad (*Dorosoma cepedianum*).

When a complete kill was attempted at Beverly Bay, a moderate wind, blowing into the work area, created an undercurrent and the chemical was readily diluted. As a result, only 8.3 pounds of fish per acre-foot of water were removed.

A summary of the results of these six treatments is given in Table 1. A checklist of fishes

found in Lakes Lavon and Bonham Park (before treatment) with their relative abundance is shown in Table 3.

Effect on water-quality characteristics

Of the 18 physical, chemical, bacteriological, and biological determinations made during this study, only four showed any significant change after the addition of the rotenone products (Tables 4 and 5). The changes found in the remaining 14 tests were either slight or seasonal and considered to be insignificant to this study. These data are from surface samples but are indicative of the changes from all depths. The only difference in samples from deeper water was that the new type persisted at or near the bottom for 2 days longer than on the surface.

There was a slight increase in total organic nitrogen believed to be due to decaying material. Daily tests were made until the taste and odor returned to normal, but the slight nitrogen increase remained after this time while the tests were being made at irregular intervals.

Usually within 2 or 3 days after the application of rotenone products there was a tendency for the turbidity to decrease. This change was especially apparent where vegetation was not a major factor and it is believed due mainly to the eradication of bottom-feeding fishes which stir up the silt deposits.

There was an increase in the number of plankton after addition of rotenone products. This buildup was believed to be caused by the reduction of plankton-feeding fishes, increased food made available by the decaying organic matter, and to the additional depth of light penetration. So many factors enter into the growth of algae that it would require an additional study to determine whether increased food would consistently cause an increase in plankters to increase in numbers. While there was an increase, the types which increased were not consistent and seemed to be dependent upon other factors such as temperature of the water, season, and light penetration.

In both the Bonham and Price Creek areas the number of bacteria per milliliter increased shortly before the threshold odor changed to "fishy." The exact cause of the increase is not known, but possible explanations may be the decomposition of dead organic material, an increase in water temperature, or the aeration of water and bottom sludge during treatment operations. Since there was no con-

Fig. 4.—Analyses of water and biological characteristics at surface of Bonham State Park Lake before and after treatment, 1959

[Chemical content expressed in parts per million; plankton in numbers per milliliter]

Item	Pre-treatment				Post-treatment					
	April 27	April 28	April 29	April 30	May 1	May 2	May 3	May 4	May 5	May 15
idity	60	68	52	26	34	2	18	6	16	2
itrogen	0.15	0.04	0.01	0.15	0.08	0.12	0.10	0.12	0.05	0.20
ic nitrogen	0.25	0.16	0.29	0.20	0.22	0.20	0.27	0.23	0.41	0.32
itrogen	0.40	0.20	0.30	0.35	0.30	0.32	0.37	0.35	0.46	0.52
ocystis	606	606	778	692	519	519	692	778	606	519
elra	—	—	15	5	39	39	78	157	234	274
errium	—	—	12	—	18	39	39	157	78	39
plankton	606	606	805	697	576	597	809	1,092	918	832
number ¹	4-mu.	30-ker.	30-ker.	22-ker.	14-ker.	7-ker.	5-mu.	5-mu.	5-mu.	5-fishy
probable number	62	13	13	62	6	6	13	13	13	23
% of bacterial colonies per milliliter	200	100	200	100	100	400	1,000	2,000	600	100

mu. = musty,
ker. = kerosene.

ing increase in the most probable number of coliform organisms, bacteria other than form constituted the increase. Unless this up was extremely great, most modern treatment plants could cope with it with difficulty.

May the bacterial count at the intake permanent water station increased about ten times over the previous analysis without other influences. This fact suggests that rising water temperature may be responsible and that the other causes may be minor. All the tests made during this study the test change was made in taste and odor the water treated. Both Bonham Lake and Price Creek changed rapidly from 5-musty to 0-threshold odor number. The emulsified rotenone product used at Bonham produced 0-kerosene odor number at all depths which for 2 days and then tapered off on the day to a 5-oily at the bottom. A fishy was detected 17 days after treatment

(Table 4). The powder applied to Price Creek produced a 30-fishy odor in 3 days, but no trace of a kerosene or oil odor was found (Table 5). The normal 5-musty odor reappeared in less than 10 days in this shallow, warm-water cove.

RESULTS OF LABORATORY STUDIES

Early in the year, before any treatment was begun, the Game and Fish Commission made samples of most of the various rotenone compounds to be used available to the North Texas Municipal Water District's laboratory. Known concentrations of the different compounds were prepared and varying dosages were applied to the raw water in an effort to predetermine, as nearly as possible, conditions that might arise as the treatment progressed. Results in laboratory experiments were duplicated very closely in the field, especially in Bonham State Park Lake and Price Creek

Fig. 5.—Analyses of water and biological characteristics at surface of Price Creek before and after treatment, 1959

[Chemical content expressed in parts per million; plankton in numbers per milliliter]

Item	Pre-treatment		Post-treatment			
	June 15	June 16	June 17	June 18	June 19	June 24
idity	66	84	46	40	40	120
nitrogen	0.01	0.01	0.01	0.00	0.00	0.05
ic nitrogen	0.20	0.19	0.22	0.25	0.24	0.27
nitrogen	0.21	0.20	0.23	0.25	0.24	0.32
ira	39	0	0	1,124	951	0
ocystis	1,643	1,643	1,297	0	0	1,038
errium	0	0	0	0	39	157
ira	39	196	118	78	0	39
ula	0	1,470	314	117	78	1,816
plankton	1,721	3,309	1,729	1,319	1,068	3,350
number	5-mu. ¹	5-mu.	7-fishy	30-fishy	22-fishy	5-mu.
probable number	240	700	700	62	6	240
% of bacterial colonies per milliliter	100	2,080	tnc. ¹	2,500	7,000	3,500

mu. = musty,
tnc. = too numerous to count.

Cove where wind and currents were of minor importance.

Noxfish was used in concentrations of 0.5, 1.0, and 1.5 p.p.m., and it was found that an odor number of 30-kerosene could be expected initially with each concentration. These 1-gallon samples of treated raw water were placed in shallow pans outdoors where weather conditions were as nearly like those at the lake as possible. Water temperature was kept within 2° C. of that in the raw lake water. Odor numbers for the samples during the first 7 days were 30-kerosene, 30-kerosene, 23-kerosene, 15-kerosene, 8-kerosene, 7-oily, and 5-musty.

Each day small portions of the sample were treated with varying dosages of chlorine and activated carbon to determine the amounts needed to reduce the number and taste-and-odor type to that normally found in raw water. Our experience showed that chlorine had little, if any, effect on reducing the odor number. It was found that 1.0 p.p.m. of activated carbon, having a detention time of 2 hours, would reduce the odor number by approximately one. In other words, 30 p.p.m. of activated carbon were required the first day and 15 p.p.m. were required the fourth day to bring the odor number to 5-musty.

Chem Fish Regular with HFN and Chem Fish Special with HFN in raw water produced an odor number of 18-kerosene with a 1.5 p.p.m. dosage, an odor number of 10-kerosene with 1.0 p.p.m. dosage, and an odor number of 8-kerosene with a 0.5 p.p.m. dosage. These odors persisted for about the same length of time as those produced with Noxfish. Chlorine was ineffective in reducing the odor number, and 1.0 p.p.m. of activated carbon per one odor number was required to reduce the odor number to its natural level.

Powdered derris root, in concentrations of 0.5, 1.0, and 1.5 p.p.m., was applied to samples of raw water, and no change in odor number or odor type was experienced. Chem Fish Synergized with HFN was not tested in the laboratory because none was available at that time.

In an effort to trace the movement and dissipation of the rotenone chemicals, the analytical procedure described by Post (1955) was tried several times, using fresh solutions and reagents according to instructions furnished, with unsatisfactory results. In several instances solutions of known concentrations of

TABLE 6.—Comparison of threshold odor number and types from surface samples of treated water

Date	Bonham State Park	Price Creek Cove	East Fork Cove
Day before treatment	4-musty	5-musty	4-m
Day of treatment	30-kerosene	5-musty	5-m
Plus 1 day	30-kerosene	7-fishy	5-m
Plus 2 days	22-kerosene	30-fishy	
Plus 3 days	14-kerosene	22-fishy	
Plus 4 days	7-kerosene		
Plus 5 days	5-musty		
Plus 6 days	5-musty		5-m
Plus 7 days	5-musty	5-musty	
Plus 8 days		5-musty	5-m
Plus 13 days			
Plus 17 days	5-fishy		
Plus 22 days		5-musty	
Plus 29 days	5-musty		

¹ Toxicants as indicated in Table 1.

rotenone were prepared, but no similarity to the expected results was obtained. Other biologists and chemists have reported similar findings, but a report of the Hodges Reservoir work at San Diego (Hoffman and Payson 1956) claimed a slightly modified test is sensitive enough to detect the amount of synergized rotenone liquid in water as close as 50 feet.

IMPLICATIONS OF FINDINGS

For water-treatment plants

From the standpoint of municipal water usage, it is felt that the greatest problem to be expected in this type of fishery work is the change in taste and odor of the water treated. While the odor number obtained using powder equaled that of the emulsion product, the odor type changed directly to fishy without the added kerosene step (Table 6). Fishy is a more natural odor for surface water supplies and is not deemed as objectionable psychologically as an equal odor number of kerosene. Water customers associate fishy water but become alarmed when chemicals or oils are found in municipal water. The powdered chemical would therefore cause taste and odor change and would be the first choice of water-plant workers.

Chem Fish Regular HFN was tried at Baptist Bay, Chem Fish Synergized HFN was used at East Fork Cove, and Beverly Bay was treated with the cold-water Chem Fish Special HFN. A slight kerosene odor was detected at both Baptist and Beverly Bays, while Chem Fish Synergized HFN used at 0.5 p.p.

TABLE 7.—Comparison of the approximate costs of rotenone products per acre-foot of water at a concentration of 1.0 p.p.m.

Rotenone products	Rotenone content	Comparative cost per unit purchase	Chemical required per acre-foot for 1.0 p.p.m.	Cost per acre-foot
Rotenone powder ¹	5 percent	\$0.35 per pound	2.72 pounds	\$0.952
Chem Fish Emulsified ¹	2.5 percent	4.85 per gallon	0.34 gallons	1.649
Chem Fish Emulsified HFN	2.5 percent synergist	5.01 per gallon	0.34 gallons	1.703
Chem Fish Emulsified ¹	2.5 percent synergist	5.54 per gallon	0.34 gallons	1.884
Chem Fish Emulsified HFN	5 percent	6.13 per gallon	0.34 gallons	2.084
Chem Fish Emulsified ¹	5 percent	7.70 per gallon	0.34 gallons	2.618
Chem Fish Emulsified HFN	5 percent	8.37 per gallon	0.34 gallons	2.846

Other brands of rotenone products have comparable costs.

had at East Fork Cove did not produce odor other than musty (Table 6). Emulsified rotenone with HFN, preferably synergized rotenone with HFN, therefore would be the best choice for municipal water treatment. When waters used for human consumption are treated with fish toxicants, there is likely to be an increase in water-production costs. Activated carbon, the material normally used to filter out water tastes and odors, costs about \$160 a ton, for carload bulk shipment, \$260 a ton when sacked in 35-pound bags. Its ranges from approximately 8 to 13 cents per pound. Laboratory tests mentioned above showed 1.0 p.p.m. of the carbon is needed to prevent each odor number increase in Lagoon water.

To treat 1 million gallons of water, 8½ pounds of carbon for each additional number would be required. If the threshold odor number changed from 5-musty to 30-fishy, approximately 250 pounds of carbon would be needed. This treatment would result in a cost increase from \$20 for bulk carbon to \$32.50 if sacked carbon is used. Since experience showed that the 30-fishy odor may stay for a maximum of 3 days, a total of about \$60 × 95 would be added to production costs for plants handling 1 million gallons of water daily. There is also a possibility that plants not having machinery to handle this additional carbon would have to modify or improve their equipment during this period. Finally there would be no additional costs for labor or other items.

In preparing plans for use of toxicants, consideration must be given to the seasons most suitable to waterworks people. Summer

months are least suitable because there is heavy water usage which is sometimes five times the normal winter consumption. This increased load means increased velocity through the plant, decreased detention time of treatment period, possible use of additional chemicals and equipment, and higher costs of chemicals. In addition, during warmer months the consumer is more likely to detect substandard water. On the other hand, it is believed that taste and odor dissipate more readily from water in the summer from possible increased aeration due to greater velocity and warmer temperatures.

While the least water usage occurs in the cold months, spring and fall consumption are not abnormally high. At these seasons the public is more likely to accept unusual tastes and odors because there are seasonal lake changes.

The decrease in turbidity, which allows greater light penetration, could result in greater plankton growth. From the standpoint of surface water treating plants, any plankton increase is viewed with suspicion, particularly if the increase is in the taste- and odor-producing types such as *Microcystis*, *Synedra*, *Anabaena*, *Oscillatoria*, and others. An increase in plankton usually associated with filter clogging, such as *Navicula*, *Cyclotella*, *Diatoma*, *Closterium*, and others, would also be undesirable.

For fisheries management

The HFN chemicals have greater cost than ordinary emulsified rotenone (Chem Fish) and the standard 5-percent powder (Table 7).



FIGURE 2.—Treating barge used for mixing and distributing powdered rotenone products.

Chem Fish Synergized, which is the least expensive of the liquid piscicides with the new carriers, costs about twice as much as powder for an equal strength treatment, while the cold-water toxicant, Chem Fish Special HFN, is three times as expensive. Some biologists believe this increased cost is compensated for by the saving in time and labor in lake treatments. The new treating barge developed in Texas' Region 1-B, however, has shown that powdered rotenone products can be applied faster and easier than most liquids (Figure 2). For municipal waters, therefore, 5-percent rotenone powder gives less trouble to the water-treatment plants and is less expensive than liquid rotenone products.

Fisheries workers have found that better fish kills can be expected when water temperatures are warm and fish metabolism is high. Summer months usually offer better field working weather, but other lake activities, such as swimming, boating, and skiing, are also at a peak during this season and may offer conflicts with summer treatments.

Since improved fishing is the ultimate goal of all lake management, there should be consideration of the availability of hatchery fish to replace those removed when a complete kill is attempted. Complete kills of fish in lakes 50 acres or larger are impossible to attain with rotenone. The plan in Texas is to release

large numbers of game fish soon after most of the undesirable species have been killed. Lakes over 10 acres in Texas are ordinarily stocked with advanced largemouth bass from the spring. Channel catfish and crappie are available as fall fingerlings. It is best, therefore, to treat bass lakes in the spring as early as possible to allow the water to warm, but not too late to obtain bass fry from the hatchery. If catfish and crappie fishing is most important, the chemical could be applied in September or October before the lakes begin to cool.

Selective treatment for shad has been most successful when lake temperatures are above 55° F. Depending somewhat on the location in the state and the depth of the lake, the temperature usually occurs in February, March and again in November and December. Normally, stocking with hatchery fish does not follow a selective kill, but competition is reduced and the game fish already present benefit by the treatment. If treatment of shad are not paramount, then Chem Fish Synergized, a toxicant recommended and widely used for shad kills, would be acceptable on the basis of the taste and odor, if the new carrier is used.

It appears from the foregoing considerations that spring or fall is the season most suited for municipal lake renovation from

point of both water-treatment plants and
eries management in Texas.

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Propagation of Northern Pike

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ABSTRACT

The procedures and techniques involved in the artificial propagation of northern pike (*Esox lucius*) at the Valley City, North Dakota, National Fish Hatchery are discussed. Twenty million to 40 million northern pike eggs are taken from wild fish each spring. The eggs are incubated in Downing-type glass jars and the "swim-up" fry are stocked in hatchery ponds at the rate of 100,000 per acre. The use of filtered water for incubation purposes increased the percentage of hatch from 20 percent in 1958 to 78 percent in 1959. Hatchery ponds are filled with water from the Sheyenne River and fertilized 2 weeks prior to the introduction of free-swimming pike. The fry grow to a length of 2-2½ inches over a period of 4-6 weeks in the hatchery ponds. Fingerlings are harvested near the end of their plankton-feeding stage to prevent serious losses from cannibalism. Pond yields vary from 0 to 90,000 fingerlings per acre with an average of 35,000 during the 1959 and 1960 production years.

The propagation of northern pike (*Esox lucius*) is a relatively new development in fish culture. Sportsmen hold northern pike in high esteem in about one-half of North American areas in which they naturally occur (Carbine, 1938; McCarraher, 1959). They are voracious predators and have been used to reduce overcrowded populations. Considerable interest in the hatchery production of northern pike has arisen as a result. It is therefore appropriate to summarize different hatchery techniques and to compare results. The propagation of northern pike follows the general procedures used in muskellunge and walleye culture where the young are usually planted as advanced fry (Johnson, 1958). The tendency for cannibalism among fingerlings and the high cost of obtaining live food required make it uneconomical to rear them to the adult stage.

CAPTURE OF SPAWNING STOCK

The adult fish are captured from wild stock each year, usually with hoop nets. At the National Fish Hatchery in Valley City, North Dakota, about 4,000 adults are captured each spring from nearby Ashtabula and Jamestown Reservoirs, with a modified hoop net or fyke net. The rectangular shape of the "hoops" prevents the wind and waves from rolling the trap. A 75-foot lead guides the fish into the mouth of the trap.

The spawning run of northern pike in North Dakota lasts from 7 to 12 days. Since most females are ripe when captured, they are stripped and released. Unripe adults are kept only a short time in holding cribs because they injure themselves by fighting the netting.

The females can be held safely for 2 days and the males for 4 or 5 days. Injections of pituitary extract to induce spawning have been tried in several states with fair success.

Huet (1952) reports that in France adults are often captured in the fall and held in acre ponds until spring to insure the availability of spawning stock. This procedure requires a good supply of live forage fish.

It is believed that under natural spawning conditions northern pike deposit all their eggs within a period of a few days. Consequently all eggs can be taken from a female in a single operation (Fabricius and Gustafson, 1955). The spawning migration starts when the water temperature reaches about 38° F. The males usually appear first in the shallow waters. The females rarely show up in numbers before the water temperature reaches 44° F. As a result of this time differential, the males are usually captured first and held until the main spawning run of the females. The males outnumber the females by three to one.

At Valley City the trapped adults are carried from the traps to a pontoon spawning barge in an aluminum boat, partially filled with water. The barge (16 by 24 feet) serves as a base for the actual spawning operation. It is equipped with eight 4- by 5-foot cribs in which the extra males and unripe females are held. On a platform 8 by 16 feet at one end of the barge, the eggs are taken, washed, and stored. The barge is enclosed with a heavy canvas to protect the operators, eggs, and fry from the weather. It has been noted that northern pike sperm cease to be active on freezing temperatures.

ARTIFICIAL FERTILIZATION

During the peak of the spawning run at Valley City, 200 to 300 females and 400 to 500 males are captured daily. The females average about 22 inches in length and produce about a pint of eggs (an average of 30,000).

The males are slightly smaller and usually produce 2 to 5 cubic centimeters of milt. Fish of approximately the same size have been reported from Minnesota and Michigan (Bryant, 1944; Franklin and Smith¹). During the peak days 5 million eggs, or 90 quarts, are taken, and the total in an average season varies between 20 and 40 million eggs.

With minor modifications the "dry method" technique for taking trout eggs is used on northern pike. It is considered unnecessary to anesthetize the adults since they are relatively insensitive in the cold water. Short, rearward strokes with the thumb and forefinger in the space just anterior to the ovarian papilla serve to eject the eggs. The strokes are gradually increased in length as the egg sac is emptied. More than 2 quarts of eggs are expressed from one pan. No attempt is made to take all the eggs, thus minimizing broken eggs, bloody eggs, and the chance of injury to the female. Special care must be taken to avoid getting milt into the egg pan because it appears to inhibit the fertilization of the eggs. Some hatchery workers wipe the fish with a towel before taking eggs or milt (Clark and Dean, 1959). This procedure is not practical at Valley City because of the large number of fish handled. Special care is taken, however, to prevent mucus from getting into the egg

pan. When expressing milt from the male, pressure should not be exerted posteriorly because milt enters the urine and is thereby forced into the eggs. Since the testes are firm, the sides of the testes must be squeezed together with the thumb and forefinger about 3 inches anterior to the vent. In this manner urine-free milt can be secured. Occasionally males are released to the holding cribs since they can be used on several successive days.

The eggs are mixed with the milt from several males by rotating the pan gently. Since large amounts of water increase the activity of northern pike sperm (Johnson, 1958),

about 1 pint of water is added to the pan of eggs and milt. Mixing is continued for about 1 minute, and the eggs, milt, and water are allowed to stand in the spawning pan for 5 minutes. Foreign material is removed by adding clear water and decanting several times if necessary.

The timing and handling is critical during the period from 10 to 20 minutes after the first water is added to the pan. Excessive handling of eggs results in an increase of egg mortality. In this respect northern pike eggs are more delicate than those of trout. Within 10 minutes after fertilization, the cleaned eggs are transferred to shallow wooden trays with plastic screen bottoms each of which holds about 1½ quarts of eggs. The trays are stacked in tiers and submerged in a tank of circulating water until the day's operation has been completed.

By use of the "dry method," the percentage of fertilized eggs obtained by different hatcheries varies from 5 to 90 percent. The highest percentage of fertilization occurs when milt is added within 3 minutes after the eggs are taken.

Fertilization may be accomplished by macerating the testes and swirling the material through the pan of eggs. This method was tried in Nebraska with an average of 25.5 percent of the eggs fertilized (McCarraher, 1959).

At Valley City the eggs are transported to the hatchery in tiered trays submerged in a drum of fresh water. Fertilized eggs have remained in transit in noncirculating water for as long as 2 hours without adverse effects.

TECHNIQUES FOR INCUBATION OF FERTILIZED EGGS

Fertilized eggs are handled in several ways prior to their placement in the hatching jars. Some hatcherymen float the eggs in screen or wire baskets in tanks of circulating water as long as 12 hours to insure hardening. Others allow only a few hours for the eggs to harden before placing them in hatchery jars or on trays.² At Valley City the eggs are hardened about 4 hours in the trays. During the water-hardening process, the eggs tend to stick together. They are screened to break up the clumps, and 2 quarts are placed in the vase-shaped Downing jars to start incubation.

¹ Franklin, Donald R., and Lloyd L. Smith, Jr. Some phases of the early life history of the northern pike, *Esox lucius* L., with special reference to factors influencing the numerical strength of the classes. University of Minnesota, 108 pp.

² Personal communication from Dewey Sorenson (1960).

Pike eggs may be handled in the same manner as trout eggs. They are "plated out" on screen trays, stacked in tiers, and placed in troughs so that water is forced to percolate up from the bottom of the trays. This technique does not disturb the eggs during incubation. Although this method results in satisfactory hatches, it is used by few hatcheries because only a limited number of eggs can be handled.

In western Europe many hatcheries use the Zoug decanter jar to incubate the eggs to the eyed stage. Eggs are either transferred to trays tiered in troughs, or they are scattered on straw submerged in water-filled troughs, for completion of incubation. The Zoug jars are large bottles without closed bottoms in which 1 to 5 quarts of fertilized eggs are placed. The bottle is held upside down and stoppered with a cork through which a nozzle is inserted. The water is introduced through the nozzle which produces a spray-like effect that keeps the eggs suspended in the water with a minimum of motion (Huet, 1952).

Water is introduced into the bottom of the Downing jars through a central tube connected to an overhead spigot. The flow of the water buoys up the eggs and keeps them rolling gently. Since northern pike eggs are heavier than the eggs of most species, more water flow is required to keep them rolling. At first the eggs are usually sticky and after 24 hours they may form solid clumps in the hatchery jars. Any attempt to break up these clumps is injurious to the eggs. After about 5 days, however, the egg masses break up and the eggs start rolling normally. If filtered water is used in the batteries, the eggs do not clump; they roll with less water flow; and they retain a "butter" color during most of the incubation period.

Filtered river water was used at Valley City during part of the incubation period in 1959 and 1960. In these 2 years, 78 and 65 percent of the eggs hatched from 42 and 22 million eggs taken. Prior to 1959, when unfiltered water was used, the hatch averaged about 20 percent. It is anticipated that through the exclusive use of filtered water the average percentage of hatch can be held close to 70 percent, a rate of success which can occur in nature under ideal conditions.³ Well water is used in Iowa to incubate the eggs with excellent results (Moen and Lindquist, 1954). In France Huet (1952) reports that the use

of "well-filtered" lake water resulted in hatches of over 70 percent.

The most desirable water temperature for the incubation of northern pike eggs appears to be 48° to 52° F. It is not always possible to maintain this temperature when a lake or river is the direct source of water supply because of considerable daily fluctuation of temperature. Sub-impounding, recirculating, and heating have been tried but none of these methods is entirely satisfactory in providing ideal temperatures. At Valley City partial or complete recirculation of the same water through the hatching jars during the cooler parts of the night and early morning for the first 10 days of the incubation period has been most satisfactory. After 10 days the season has usually advanced enough so that water temperatures do not fluctuate severely.

The volume of water flowing into the hatching jars should be sufficient only to roll the eggs gently since rolling too rapidly will damage the developing embryos. Infertile or dead eggs are lighter in both weight and color, and after about 5 days they collect at the top of the rolling egg mass. If the dead eggs do float out of the jar they must be siphoned off to prevent the development of fungus and formation of molded clumps.

When the eggs reach the eyed stage, they are screened and washed. Screening breaks up the dead eggs and the remainder can be expected to hatch. Three quarts of eyed eggs are placed in each jar. After hatching, which takes 12 to 17 days, the egg membranes are removed to the top leaving the fry in the jar. Newly hatched fry measure about 0.4 inch in length and are yellowish-tan in color. With the exception of the pectorals, the fins are about fully developed. There is no mouth or gill development, and the gills have not yet formed. The fry have an adhesive papilla near the anterior part of the head and in front of the eyes.

Some hatcherymen transfer the fry to tanks of quiet water or tanks with submerged rocks or aquatic plants where they scatter over the area and cling motionless to some object by means of the adhesive papillae (Cox, 1954; Glover and Sorenson, 1960; Sorenson, 1960). In this quiescent state, the fry hatch at a 45° angle for about 5 days. During this period the yolk sac is absorbed; the fins develop; the gill and mouth operculum become visible; the fry grow to a length of 0.6–0.8 inch; and their color changes from dark brown. The fry release their hold

³ See footnote 1.

ne a normal swimming position. They are now called "swim-up" fry.

Valley City the newly hatched fry are in the hatchery jars during the 5-day period while the yolk sac is being absorbed. Slightly more water is needed to roll the fry and keep them well separated so as to prevent smothering. As the fry development advances to the "swim-up" stage, a few may be noted swimming in a horizontal position above the surface of the gently rolling mass of fry in the jar. The creation of a slight disturbance in the water or a tap on the jar at this stage will result in a chain reaction of excitement through the entire mass. The fry must be kept at this stage because they are ready to feed and because they become very active and leave the jar.

In Nebraska (McCarraher and Dawson, 1954) and Ohio (Clark and Dean, 1954) the fry are placed in ponds to spawn naturally. Usually a ratio of two males for each female is used. Sometimes selected areas in these ponds are covered with straw. The adults are allowed to spawn and after 6 or more weeks the ponds are drained and the fingerlings are harvested. The results are highly variable. In Nebraska a pond containing six females, 102 fingerlings were harvested. In another pond with three females, the return was 28 fingerlings.

In Minnesota a modification of this pond method is used successfully.⁴ A suitable shallow bay of a lake is sealed off by a dike, and the adults are placed in the area in the winter. The fingerlings are removed by seining in the late summer. The results are difficult to evaluate, other than to state that the cost of production is held to a minimum.

PLANTING THE FRY

As soon as the fry start active feeding, they require live food in the form of microcrustaceans (Franklin and Carbine, 1951; Franklin and Smith, 1954). Limited success has been obtained by holding the fry in troughs or tanks and feeding them microcrustacea or plankton, but only a small number of fry can be raised in this manner. At Valley City fry are planted in ponds varying in size from $\frac{1}{2}$ to $3\frac{3}{4}$ acres and ranging 2 $\frac{1}{2}$ feet deep. The ponds are filled 1 week or 10 days prior to planting the fry with water from a pool created in the Sheyenne River by a low dam. If the ponds are to be

fertilized, this is done at the time they are filled. The best results from fertilizing ponds have been obtained by using a combination of tankage (50 pounds) and torula yeast (25 pounds) per surface acre. Ammonium nitrate is also effective in producing aquatic fauna. No phosphate or potash is used because the water in this region contains a sufficient amount of these ions. No specific combination of different fertilizers has been shown to excel in the production of microcrustacea.

The fry are planted in the Valley City ponds at the rate of 100,000 per surface acre, a rate which is much higher than that used in most hatcheries. In Europe Huet (1952) reports that 200 to 400 fry are planted per acre and that a harvest of 100 fingerlings after 6 weeks is considered a good crop. At Valley City, where the technique of rearing fingerlings is not yet fully developed, the yields vary from 0 to 90 percent of the planted fry with an average of about 35 percent.

To discourage cannibalism fry of identical ages are placed in each pond. They start feeding on the microcrustaceans soon after they are planted. After 8–12 days larger aquatic organisms, such as *Daphnia*, larger Cladocera, Ostracods, and small insects or insect larvae, are utilized. During the fourth week, when the fry have grown to a length of 2–2 $\frac{1}{2}$ inches and average about 1,500 per pound, an important change in the food habits occurs. Even though microcrustaceans, *Daphnia*, and insect larvae are still abundant in the pond, they are not fully eaten. An occasional fish can be found in the stomachs of the larger fingerlings. Continued holding in small rearing ponds requires the addition of forage fish. This practice is questionable economically because northern pike fingerlings seem quite able to compete with other fish when planted in natural waters. Franklin and Smith (MS) found that the strength of a year class could be determined by the numbers of pike reaching 1 $\frac{1}{2}$ inches in length.

A few states plant the fingerlings in large, shallow, fertile ponds or diked-off bays. When they reach the stage of advanced fingerlings, about 12 inches long, they are harvested by draining the bays or seining the ponds. Wisconsin has had considerable success in harvesting northern pike in large ponds by the use of an electro-fishing gear called a "boom shocker."⁵

⁴ Personal communication from Hjalmar O. Swenbeck (1960).

⁵ Personal communication from Charles N. Lloyd (1960).

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Food and Distribution of Lake Whitefish in Lac la Ronge, Saskatchewan¹

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ABSTRACT

Lake whitefish, *Coregonus clupeaformis* (Mitchill), of Lac la Ronge, Saskatchewan, were studied from 1948 to 1954. Stomach contents of 1,606 fish from the main lake and 607 from Hunter Bay were analyzed. In the main lake from 40 to 60 percent of the food consisted of chironomid larvae with sphaeriids and caddisfly larvae being other important items. In Hunter Bay amphipods were the chief food and chironomid larvae and sphaeriids shared second place. Abundance and availability of food organisms seemed to determine the type of food utilized. In the early summer whitefish were widely scattered in Lac la Ronge. As the surface water warmed, the fish moved into deeper water apparently responding to temperature changes. In the main lake during July, August, and early September they were concentrated between the depths of 15 and 27 meters. Water temperature ranged from 11° to 14° C. In Hunter Bay during midsummer fish were abundant from 15 to 35 meters where temperatures were usually 8° to 11° C. Whitefish were more active during the night than during the day.

INTRODUCTION

Lac la Ronge is located 180 miles north of Regina, Saskatchewan, and a short distance south of the Churchill River in the center of Saskatchewan. The lake (Figure 1) consists of two water bodies, the main lake and Hunter Bay, which are connected by a narrows 150 yards wide. The area of the main lake is 453, and of Hunter Bay 50 square miles. Only 15 percent of the volume of water in the main lake is less than 15 meters. Hunter Bay is much deeper than the main lake, 40 percent of the volume of water below the 15-meter level. The relative areas of various depth zones and relative volume of water at different depth strata have been published by Rawson and Atton (1953). The maximum mean depths of the main lake are 38 and 20.7 meters and of Hunter Bay 42 and 20.7 meters.

FEEDING HABITS OF WHITEFISH

Major samples for the study of the food of lake whitefish (*Coregonus clupeaformis*) were collected during the summers of 1948, 1949, and 1954. Supplementary collections were made in October 1953 in the main lake and in February 1954 in Hunter Bay. Stomach contents of 1,601 whitefish from the main lake and 556 from Hunter Bay taken in gill nets were examined. The fish ranged from 8 to 28 inches in fork length. In the years 1948, 1949, and 1950 the data were collected by the survey parties of the Department of Natural Resources of the Province of Saskatchewan. During the years 1953 and 1954

the author made collections and analyzed the data available up to 1954.

During the summer months of 1948, 1949, and 1954 stomachs of whitefish from the main lake contained mostly chironomid larvae (39 to 64 percent by volume). Other food organisms, in order of abundance, were sphaeriids, caddisfly larvae, and mayfly nymphs. Plankton made up 15 percent of the food items in 1949. Small quantities of amphipods were recorded from almost every sample (Table 1). Corixids (about 2 percent) and traces of water mites were also found. In October 1953 five additional whitefish in near-spawning condition were also examined. Four of the stomachs were empty, and one had equal amounts of amphipods and insect larvae. This suggests that whitefish feed very little with the approach of the spawning period.

In Hunter Bay during the summer months of 1948, 1949, and 1954 amphipods (*Pontoporeia* and a few young *Gammarus*) were the chief food, constituting from 44 to 90 percent by volume of the stomach contents. Chironomid larvae and sphaeriids shared the second place as food items (Table 1). In February 1954, 51 additional whitefish taken from the commercial catches were also examined. Forty-six of them had empty stomachs, and the remaining five contained 90 percent amphipods and 10 percent chironomid larvae.

Adult whitefish are primarily bottom feeders, although Dymond (1926) and Sprules² pointed out that occasionally they feed away

¹ From a thesis submitted for the degree of Master of Science at the University of Saskatchewan, April 1955.

² Sprules, W. M. (1945) The rate of growth and food of whitefish, *Coregonus clupeaformis*, in Heming Lake, Manitoba. Manuscript report 463, Central Fish. Res. Sta., Fish. Res. Bd. Canada, 12 pp.

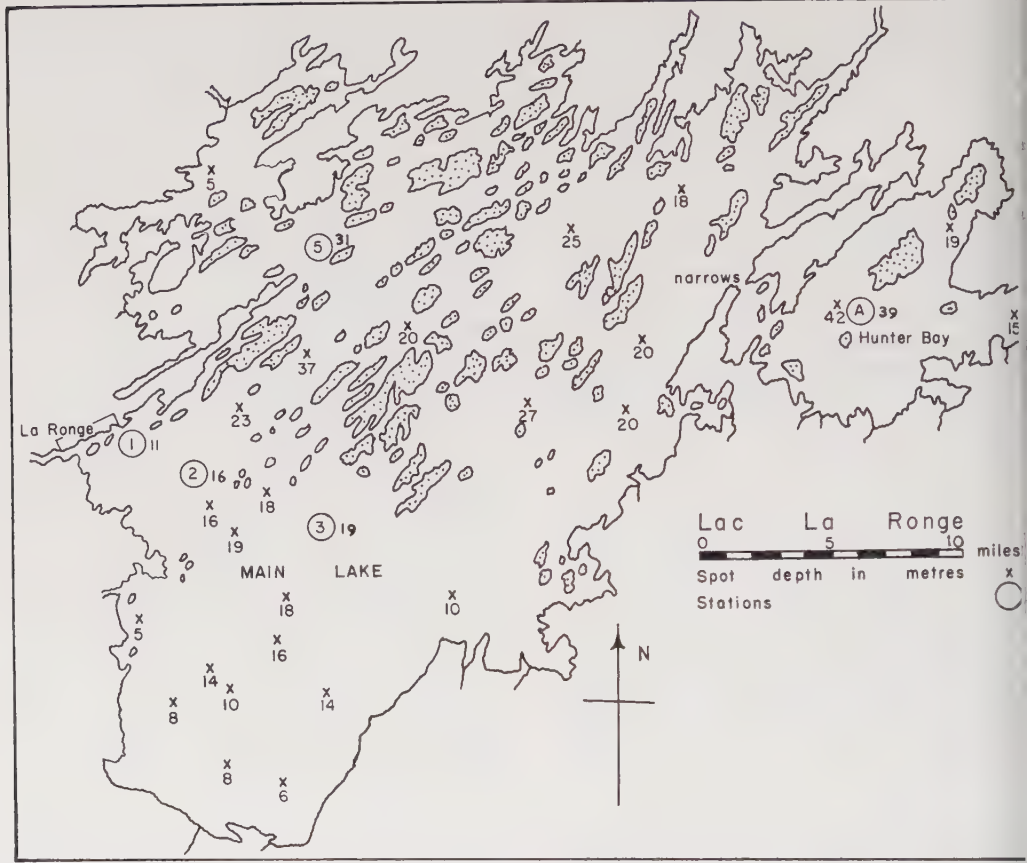


FIGURE 1.—Map of Lac la Ronge, Saskatchewan, showing localities mentioned in the text. Depth of stations indicated at right of symbol.

from the bottom and even at the surface. Brunson and Newman (1951), studying the food of whitefish from Yellow Bay, Montana, and Frankenberger (1957), studying the whitefish and ciscoes in the lakes in Wisconsin, showed that whitefish fed mostly on insect larvae with molluscs forming the next most

important food item. The food of whitefish in Hunter Bay was found to be similar to reported by Larkin (1948) for Great Slave Lake. He concluded that 60 percent of whitefish food was *Pontoporeia*. The remaining 40 percent was shared by sphaeriids, gastropods, and chironomid larvae. The varia-

TABLE 1.—Important food items found in the stomachs of lake whitefish in Lac la Ronge during the summer of 1948, 1949, and 1954

[Expressed as percentage of volume;¹ items less than 2 percent not included]

Date and location	Chironomid larvae	Amphipods	Sphaeriids	Caddisfly larvae	Mayfly nymphs	Fish remains	Plant remains
Main lake							
1948	57	3	25	3	2	3	—
1949	39	—	29	10	—	—	—
1954	64	4	16	7	3	6	—
Hunter Bay							
1948	6	90	3	—	—	—	—
1949	19	51	26	2	—	—	—
1954	26	44	26	—	—	—	—

¹ Samples of October 1953 and February 1954 not included.

FIGURE 2.—Average number of lake whitefish caught per net set at different depths in Lac la Ronge during the years 1948, 1949, 1950, 1953, and 1954

Item	Depth (meters)							
	0-5	5-10	10-15	15-20	20-25	25-30	30-35	35-40
Main lake								
Number of sets	16	32	17	35	11	7	—	—
Number of fish per set	25.6	24.3	63.4	117.7	76.0	93.7	—	—
Hunter Bay								
Number of sets	1	2	—	7	9	7	5	4
Number of fish per set	0	3	—	79.2	67.5	69.8	93.0	53.7

The composition of the stomach contents of whitefish suggests that there is little selectivity and that fish feed on the species of bottom organisms in proportion to their abundance.

REGIONAL VARIATION IN VERTICAL DISTRIBUTION

The vertical distribution of lake whitefish was analyzed in the main lake and in Hunter Bay from late May to early September in 1948, 1950, 1953, and 1954 (Table 2). For the years bi-weekly depth distribution of whitefish is shown in Figures 2, 3, and 4. The numbers of fish in individual catches were plotted against the average depths. The average of two or three depths at which each standard gang of gill net was set was termed average depth.

Main lake

During May and early June 1948 (Figure 2) whitefish catches were large at all the depths sampled. In early June 112 fish were caught at an average depth of 6 meters and 40 fish at 15 meters. In the second half of June, July, August, and early September, larger numbers of fish were usually caught in deeper

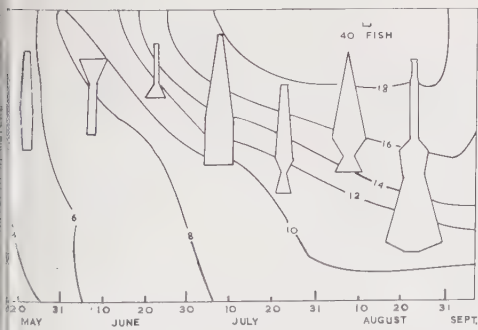


FIGURE 2.—Depth distribution of whitefish (polygons) caught by the standard gang sets, and temperature in degrees centigrade (isotherms) in the main lake during the summer of 1948. The polygons represent bi-weekly distribution of fish. The third summer catch is included with August.

water, as was demonstrated during the second half of August when 262 whitefish at 28 meters and 4 fish at 6.5 meters were caught.

In 1954 (Figure 3) there was a somewhat similar distribution pattern. An unusual situation was observed in early July when the number of fish caught was somewhat higher in shallower water than in deeper water. In the years 1949, 1950, and 1953 the same general pattern of distribution was observed from late May to early September as in 1948. Whitefish were caught at almost every depth, but the catches increased with depth and were highest between 15 and 27 meters (Table 2).

Hunter Bay

Data for the combined years of 1948, 1949, 1953, and 1954 showed that in early June fish were scattered evenly at different depths (Figure 4). One hundred and twenty-eight and 51 fish were caught at an average depth of 18.5 and 34 meters, respectively. In the latter part of June, in July, August, and early September, small numbers of fish were caught in shallow water and larger catches were made in deep water. During early August 101 fish at an average depth of 30.5 meters and 4 fish at 6.1 meters were taken.

In three sets in Hunter Bay during the four years almost no whitefish were netted in shallow water. The highest average catch (93

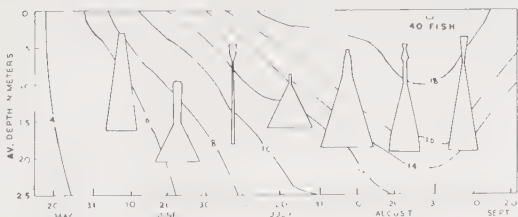


FIGURE 3.—Depth distribution of whitefish (polygons) caught by the standard gang sets, and temperature in degrees centigrade (isotherms) in the main lake during the summer of 1954. The polygons represent bi-weekly distribution of fish.

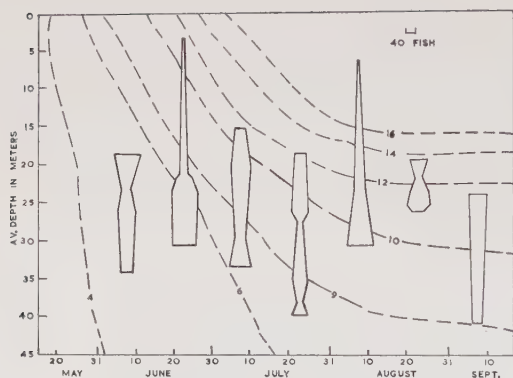


FIGURE 4.—Depth distribution of whitefish (polygons) caught by the standard gang sets, and temperature in degrees centigrade (isotherms) in Hunter Bay during the summer of 1948, 1949, 1953, and 1954 combined. The polygons represent bi-weekly distribution of fish. The isotherms in broken lines represent averaged temperatures for all the years.

fish per set) was taken between 30 and 35 meters. Below this depth the catch declined. Fish were most abundant between 15 and 35 meters (Table 2).

RELATION OF FISH DISTRIBUTION TO TEMPERATURE

Surface and bottom temperatures were taken at stations 1, 2, 3, and 5 in the main lake and at station A in Hunter Bay. Water temperatures at the locations of catches were also taken. In most cases temperatures at about midway between surface and bottom were also recorded. In Figures 2, 3, and 4 isotherms are drawn from data taken at stations typical of the waters. In general, the thermal stratification was established in Lac la Ronge about the last week of June or early July. Before that period the water was more or less uniform in temperature throughout the lake, and whitefish were usually caught at all depths sampled. With the advance of summer, temperature tolerance of whitefish changed considerably and they moved to deeper water.

Main lake

In May 1948 (Figure 2) fish were caught at water temperatures between 4° and 6° C. (available range), but by the end of June they were concentrated in water between 8° and 12° C. During July to early September they were abundant where water was between 11° and 14° C.

In 1954 fishing commenced in early June when the temperature range (5° to 8° C.) was

lower than at the corresponding time in other years. The maximum number of fish caught where temperature was between 5° and 6° C. (Figure 3). During the first half of July 1954 the number of fish was slightly greater in shallower water. It seemed that during the thermal stratification of the lake whitefish were concentrated in water where the temperature was about 12° to 13° C. This behavior was also noticed in the summer of 1953. In late September and early October whitefish moved back into shallow water.

Hunter Bay

In Hunter Bay during late May and early June whitefish were dispersed in water with temperatures between 4° and 7° C. (available temperature range). Maximum catches in July were made where water was between 9° and 12° C. and in August and early September from 9° to 12° C. In Hunter Bay whitefish were concentrated in water between about 10° and 11° C. In view of this distribution it seems probable that the whitefish in the main lake would have gone deeper to reach cooler water had it been available. The preferred temperature for whitefish in the main lake was perhaps nearer to 11° C. than to 13° or 14° C., although they flourished well enough in the latter.

In Lake Opeongo, Kennedy (1943) found that whitefish could be caught at all depths in May. In July the fish were taken from depths of 20 to 50 feet, while in September in 50 to 600 feet. He also found that whitefish showed a preference for water having a temperature of higher than 7° C.

EFFECTS OF DISSOLVED OXYGEN ON FISH MOVEMENT

Dissolved-oxygen levels may limit fish movement, particularly during the summer months in lakes which have strong thermal stratification. There was no evidence that whitefish in Lac la Ronge had to move because oxygen level was low. At no time of the year is oxygen supply reduced to a lethal level (Table 3). On August 10, 1949, at station 3 the minimum bottom oxygen level of 2.9 cubic centimeters per liter was unusual, as was the case on June 2, 1950, when the surface and bottom oxygen concentration was 9.4 and 9.3 centimeters per liter, respectively. Hunter Bay has a plentiful oxygen supply throughout the year (Table 3).

3.—Range of surface and bottom oxygen (in cubic centimeters per liter) in Lac la Ronge during the years 1948, 1949, 1950, 1953, and 1954

Year	Station	Surface oxygen		Bottom oxygen	
		Mini- mum	Maxi- mum	Mini- mum	Maxi- mum
Lake					
1948, 1953	1, 2	5.1	8.2	4.5	8.2
1948, 1949, 1950,					
1953, 1954	3	5.1	8.2	4.5	8.2
1948, 1950, 1953	5	4.5	8.2	3.1	8.2
Flat Bay					
1948, 1949, 1950,					
1953, 1954	A	5.9	8.9	4.7	8.8

DAILY MOVEMENT OF WHITEFISH

The daily pattern of whitefish movement in Lac la Ronge was observed on September 4, 1954, by the author and from August 30, 1955, by Rawson (1956). The combined data for the 2 years showed that 267 whitefish were caught in 6 nights whereas 34 were caught in 6 days. Hart (1931) stated that in Lake Nipigon whitefish were caught in greater numbers during the night than during the day. These observations suggest that whitefish were more active during the night, or probably avoided gill nets during the day.

ACKNOWLEDGMENTS

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Year-Class Distribution of Walleyes Collected by Five Types of Gear

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ABSTRACT

Year-class distribution of fin-clipped walleyes (*Stizostedion v. vitreum*) recovered in trap nets during the 1959 spawning run in Oneida Lake was nearly identical to the year-class distribution of marked walleyes released during the preceding 2 years. This indicates trap nets fished during the spawning run took various age groups in proportion to their abundance in the spawning population. Age distributions of mature walleyes taken in the summer and fall of 1958 and 1959 by shocking, trawling, gill-netting, angling, and trap-netting were compared to the age distribution of the 1959 spawning run. Samples taken by shocking, trawling, gill-netting, and summer angling showed about the same age structure as the spawning population. Trap nets fished in the fall and winter ice-fishing appeared to select the older age groups in the population.

INTRODUCTION

Accurate estimates of population parameters frequently require samples which are representative of the age or size distribution of the population. Several studies (Watt, 1956; Latta, 1959) have detected a tendency for trap nets to select the larger and presumably older fish in the population. Cooper (1952) and Sullivan (1956) noted that stream shockers also select the larger fish and emphasized the need for adjusting population estimates. This paper compares the age distribution of walleyes taken by trap net, shocker, gill net, otter trawl, and angling in Oneida Lake during 1957, 1958, and 1959 for evidence of gear selectivity.

Oneida Lake, located in central New York, has an area of 51,000 acres, a length of 20 miles, and a maximum width of 5 miles. Maximum depth is 55 feet with 25 percent of the area under 12 feet deep. The present data were collected in the course of estimating the walleye population and related studies. Samples of spawning walleyes were taken in trap nets set at right angles to the lake shoreline near the mouth of Scriba Creek and the mouth of Fish Creek. Large spawning runs enter both streams. Walleyes trap-netted near the mouth of Scriba Creek were fin-clipped and released after fish-cultural operations. Recoveries of marked fish were made by gill-netting and trawling in the deeper areas of the lake during July and August and by trap-netting and shocking along the shoreline in October and November of each year. Seasonal changes in the depth distribution of walleyes necessitated the use of several types of gear. Since all

types of gear could not be fished simultaneously nor in the same area of the lake, it is not possible to distinguish between selectivity caused by differences in the response of various age groups to the gear and difference in the distribution of age groups available to the gear.

COLLECTING GEAR AND METHODS

Nylon gill nets used in the summers 1958 and 1959 were 500 feet long with end lengths of 2-, 2½-, 3-, 3½-, and 4-inch stretch mesh. Gill-net sets were made at 15 sets scattered throughout the lake in water 15 to 45 feet deep. Trawling was limited to flat areas in the central portion of the lake where water depths were 20 to 40 feet and the bottom was comparatively smooth. The 30-foot beam trawl-type trawl used was constructed with 1½-inch stretch mesh in the cod end and 3-inch stretch mesh in the body and wings.

A boom-type electric shocker was operated at night along the entire shoreline in October and November, 1958 and 1959. The electric system consisted of five ½-inch copper cables 8 feet long, suspended from booms in front of the boat and spaced at 6-foot intervals. Power source was a 5-kilowatt, 230-volt AC generator.

In November 1958 and 1959 five trap sets were made in the eastern half and sets in the western half of the lake. Trap were set at right angles to the shore at depth of 6 to 10 feet. Nets were constructed of 125- to 150-foot leads and 25-foot wings of 3-inch stretch mesh. Dimensions of the varied from 4 by 6 to 8 by 8 feet with 2-inch stretch mesh. Trap nets of the same type and mesh size were set near the mouth of Scott Creek and Fish Creek during the spawning run.

¹Contribution of Federal Aid to Fish and Wildlife, Project F-17-R, New York.

TABLE 1.—Year-class distribution of trap-net samples of spawning walleyes fin-clipped at Scriba Creek in 1957 and 1958 and distribution of clipped walleyes recovered in trap nets at Scriba Creek in 1959

[Percentage of total in parentheses]

Released April 1958 and recovered 1 year later

Sample	Year class					Chi square ¹	d.f.
	1955	1954	1953	1952	1951 and older		
males released	24 (2.4)	698 (69.8)	20 (2.0)	151 (15.1)	107 (10.7)	3.11	4
males recovered	12 (1.8)	524 (73.1)	15 (2.1)	101 (14.1)	65 (9.1)		
females released	0	120 (24.0)	5 (1.0)	206 (41.2)	169 (33.8)	5.86	3
females recovered	0	75 (31.6)	2 (0.8)	80 (33.8)	80 (33.8)		

Released April 1957 and recovered 2 years later

Sample	Year class		Chi square ¹	d.f.
	1954-52	1951 and older		
males released	290 (58.0)	210 (42.0)	1.99	1
males recovered	191 (63.0)	112 (37.0)		
females released	112 (28.0)	288 (72.0)	0.02	1
females recovered	24 (28.6)	60 (71.4)		

Test of homogeneity.

Age composition of the angling catch is based on samples of walleyes examined during the creel census. Census was conducted during the summer and during the period of ice-angling.

Samples were taken from samples of the catch by each type of gear and from walleyes caught in trawlers. Age composition of the catch of walleyes over 12 inches total length was determined from examination of scales. Nearly all Oneida Lake walleyes reach 12 inches in length in their third or fourth growing season (age II+ or III+). The year classes of 1952 to 1955, inclusive, exhibited distinct and easily recognized growth patterns which assured accurate assessment of age. Earlier year classes were combined because there were difficulties in aging and small numbers were caught.

AGE DISTRIBUTION OF CATCH

Walleyes trap-netted near Scriba Creek during April 1958 were identified by removing the left ventral fin. Age distribution of the 151 marked fish released was estimated from scales from a sample of 1,000 males and 1,000 females. During the 1959 spawning run the samples were obtained from all left-

ventral-clipped walleyes recovered in trap nets set at Scriba Creek. The year-class distribution of samples of males and females marked and released in 1958 was compared to the year-class distribution of left-ventral-clipped walleyes recovered in 1959 for evidence of trap-net selectivity (Table 1). Similarly, year-class distribution of right-ventral-clipped walleyes released in April 1957 was compared to recoveries of right-ventral-clipped walleyes in the 1959 spawning run (Table 1). Year-class distributions of left- and right-ventral-clipped fish at release and of those recovered in 1959 are very similar. Apparently trap nets set during the spawning run sample the various age groups in proportion to their abundance. The close agreement between the age structure of marked fish at release and recovery also implies that mortality rates were uniform for these age groups or mortality rates were too low to modify the age distribution appreciably between release in 1957-58 and recovery in 1959.

Since trap nets appeared to take marked walleyes of various ages in proportion to their abundance in the spawning population, it is logical to compare samples taken with other

TABLE 2.—Year-class frequency distribution of spawning walleyes trap-netted near Scriba Creek and Fish Creek in April 1959

Sex	Area	Year class				Total	Chi square ¹
		1954	1953	1952	1951 and older		
Male	Fish Creek	164	1	20	15	200	0.37
	Scriba Creek	410	4	46	40	500	
Female	Fish Creek	162	2	25	11	200	0.21
	Scriba Creek	408	3	58	31	500	

¹ Test of homogeneity.

gear in 1958 and 1959 with the age structure of the 1959 spawning run. All age IV+ (1954 year class) and older fish examined in the fall of 1958 were sexually mature and should have been vulnerable to nets fished during the 1959 spawning run. Age distribution of the 1959 spawning population is based on examination of scales from 500 males and 500 females age V and older netted at Scriba Creek and 200 of each sex trap-netted at Fish Creek. Year-class distributions in these populations are similar (Table 2) and probably representative of other spawning populations in Oneida Lake. In combining equal numbers of males and females it is assumed that the sex ratio in the population is 1:1. Deviation from a 1:1 sex ratio would not materially

affect the analysis since the age distribution of males and females in the 1959 spawning run were nearly identical.

Table 3 shows the year-class distribution of the 1959 spawning run and the year-class distribution of the catch in other gear fished in 1958 and 1959. Differences in year-class distribution were evaluated by chi-square test of homogeneity comparing the spawning run sample with the catch in other gear in a 2 by 4 contingency table. Age structures in samples taken by shocking, gill-netting, and summer angling agree closely with the year-class distribution of the spawning run. Samples of 1954 (age IV+ in 1958) and earlier year classes taken by these gear are apparently not seriously biased by gear selectivity. Tr

TABLE 3.—Year-class frequency distribution of walleyes in 1959 spawning run collected in trap nets and the year-class frequency distribution of walleyes taken in gear fished during summer and fall of 1958 and 1959 in Oneida Lake

[Percentage of sample of year class shown in parentheses]

Sample and year taken	Year class				Total number	Chi square ¹
	1954	1953	1952	1951 and older		
Spawning run (1959)	1,144 (81.7)	10 (0.7)	149 (10.6)	97 (6.9)	1,400	
Shocker (1959)	592 (81.5)	4 (0.6)	72 (9.9)	58 (8.0)	726	1.18
Shocker (1958)	282 (77.7)	4 (1.1)	42 (11.6)	35 (9.6)	363	4.15
Gill net (1959) ²	261 (85.6)	0 (0.0)	27 (8.8)	17 (5.6)	305	2.59
Gill net (1958)	202 (82.1)	1 (0.4)	28 (11.4)	15 (6.1)	246	0.64
Trap net (1959)	220 (70.5)	4 (1.3)	59 (18.9)	29 (9.3)	312	21.22***
Trap net (1958)	140 (65.1)	2 (0.9)	33 (15.3)	40 (18.6)	215	40.35**
Trawl (1959)	411 (77.8)	3 (0.6)	67 (12.7)	47 (8.9)	528	4.04
Trawl (1958)	253 (73.3)	5 (1.4)	56 (16.2)	31 (9.0)	345	13.08*
Angling (Summer 1959)	278 (83.2)	3 (0.9)	32 (9.6)	21 (6.3)	334	0.65
Angling (Winter 1958-59)	270 (72.4)	2 (0.5)	57 (15.3)	44 (11.8)	373	17.55**

¹ Tests of homogeneity compare samples collected by each gear with year-class distribution of spawning run sample.
² Chi-square value computed by combining 1953 and 1952 year classes.
³ * Denotes significance at 0.05 probability level; ** significance at 0.01 level.

TABLE 4.—Year-class frequency distribution of fin-clipped walleyes trap-netted and released in April 1958 and age distribution of marked walleyes recovered in summer and fall of 1958 and 1959 by shocking, trap-netting, and trawling

[Percentage shown in parentheses]

Group	Year class			Total
	1954-55	1952-53	1951 and older	
Released marked	12,743 (62.3)	4,552 (22.2)	3,156 (15.4)	20,451
Recovered shocker	101 (68.2)	29 (19.6)	18 (12.2)	148
Trap net	20 (51.3)	9 (23.1)	10 (25.6)	39
Trawl	26 (65.0)	8 (20.0)	6 (15.0)	40

samples do show a highly significant (chi-square 21.22 in 1959 and 40.35 in 1958) difference from the age structure of the 1959 spawning run. Older age groups of walleyes are apparently more vulnerable to trap nets fished in the fall than to trap nets operated during the spawning run, although the same nets were employed. This difference emphasizes the need to evaluate gear for evidence of age or size selectivity under the conditions in which it is employed in any study where knowledge of a population's age structure is important.

Both the 1958 trawl and the 1958-59 winter fishing samples contained a higher proportion of older age groups than were observed in the 1959 spawning run. Mesh selection may account for the predominance of older fish in the 1958 trawl sample. It was observed in the summer of 1958 that small age-IV walleyes (1954 year class) were occasionally caught in the 3-inch mesh of the trawl wings, indicating that some escapement occurred. By the summer of 1959 the 1954 year class was probably fully vulnerable which would explain the close agreement between the 1959 trawl sample and the sample of the spawning

run. The high proportion of older age groups in the winter angling catch is difficult to rationalize, since the summer angling and the spawning run samples were similar in age structure. Both the method of fishing and the distribution of fishing pressure, however, are different in winter and summer. Either or both factors in addition to seasonal difference may affect the vulnerability of different age or size groups to angling gear.

Fin-clipped walleyes released in April 1958 and recovered by shocking, trawling, and trap-netting in the summer and fall of 1958 and 1959 were aged from scale samples. Year-class distribution of recaptures taken by shocking and trawling was similar to the year-class distribution of marked fish released in 1958 (Table 4), but trap nets showed a tendency to select the older marked walleyes. Although relatively small numbers of clipped walleyes were recovered, they support conclusions reached from the comparison of age distribution of the 1959 spawning run and the catch in gear fished in 1958 and 1959.

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Walleye Egg Survival During Incubation on Several Types of Bottoms in Lake Winnibigoshish, Minnesota, and Connecting Waters¹

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ABSTRACT

Survival of naturally spawned walleye (*Stizostedion vitreum vitreum*) eggs to pre-hatching stage was determined on five bottom areas of Lake Winnibigoshish, Minnesota, and connecting waters over 4 years. These bottom types included soft muck, sand, gravel, rubble, and boulders. Egg sampling was done at intervals throughout the incubation period and estimates of egg abundance made shortly after the completion of spawning and at or near the eyed-egg stage. Initial fertility of walleye eggs was high (96-100 percent), but the percentage of live eggs declined steadily during incubation. During the eyed-egg stage, however, there was an apparent increase in the percentage survival because of disappearance of dead eggs. Egg survival was best on gravel-rubble, both as percentage survival and numbers of eggs surviving the eyed stage. Survival of eggs on improved gravel-rubble bottom was as high as 35.7 percent but on muck bottom was as low as 0.6 percent. Survival on better bottoms of gravel and rubble averaged 25 percent. Abundance of eggs on sand bottom to which gravel and rubble had been added was more than 10 times that observed previously, and survival of eggs on the improved bottom increased fivefold. Length of incubation period, which was determined by water temperature, was a factor in egg survival. Walleyes selected gravel bottom for spawning when it was available, and most eggs were deposited in water from 12 to 30 inches deep. Low water levels in the spring of 1958 made much former spawning area unavailable and may have been a factor in a weak 1958 year class.

INTRODUCTION

Spawning activities of the walleye (*Stizostedion vitreum vitreum*) and spawning areas used have been described by O'Donnell (1942),^{2,3} Derback (1947), Eschmeyer (1950), Niemuth, Churchill, and Wirth (1959), and Forney (1960).⁴ These spawning areas are often gravel riffles in streams or gravelly shoals in lakes. Exposures of gravel suitable for spawning sites, however, are scarce in many Minnesota walleye lakes, and in such lakes walleyes spawn on other bottom types. The selection of spawning areas and success of spawning on several bottom types was studied from 1956 through 1959 on Lakes Winnibigoshish (70,140 acres), Big Cutfoot Sioux (2,436 acres), Little Cutfoot Sioux (360 acres), Little Little Cutfoot Sioux (240 acres), and immediately connected waters in north-central Minnesota. These waters, which

lie in a rolling forested area of glacial soils, comprise most of a Mississippi River headwater reservoir of 74,500 acres (Figure 1). They are hard-water lakes with a total alkalinity of about 150 p.p.m.

Summer angling catch of walleyes from these lakes (Figure 1) is about 2 pounds per acre per year. The walleye catch was 113,000 pounds in 1957 and 176,000 pounds in 1958 and made up 49 percent of the total catch. Additional species taken, in order of abundance, were northern pike (*Esox lucius*), yellow perch (*Perca flavescens*), rock bass (*Ambloplites rupestris*), and muskellunge (*Esox masquinongy*).

Many walleyes spawn on the fine sand, silt, and muck, or muck and detritus bottoms in the smaller lakes. In the two larger lakes, Big Cutfoot Sioux and Winnibigoshish, walleye spawning is restricted mostly to firm bottom of mixtures of rubble, gravel, boulders, and sand. Some connected streams are also used for spawning. In slow-flowing First River (Figure 1) fine sand and muck-detritus bottoms are utilized, but in the faster Third River spawning is mostly on gravel bars and riffles.

SAMPLING STATIONS AND METHODS

The sampling stations shown in Figure 1 were selected on the basis of bottom type information obtained from preliminary egg collecting, and the location of concentration

¹ Minnesota Department of Conservation, Fisheries Research Investigational Report No. 224.

² O'Donnell, D. John. (1942) The walleyed pike run in Knutson Creek. Wisconsin Conserv. Dept., 3 pp. (typewritten).

³ O'Donnell, D. John. (1942) A study of the natural propagation of walleyed pike in Devils Lake, Burnett County, Wisconsin. Wisconsin Conserv. Dept., Prog. Rept. 1 (typewritten).

⁴ Forney, John L. (1960) A study of conditions influencing year-class strength of pikeperch in Oneida Lake. New York Div. Fish and Game, Job Completion Rept., April 1, 1959 to March 31, 1960. Dingell-Johnson Proj. F-17-R-4.

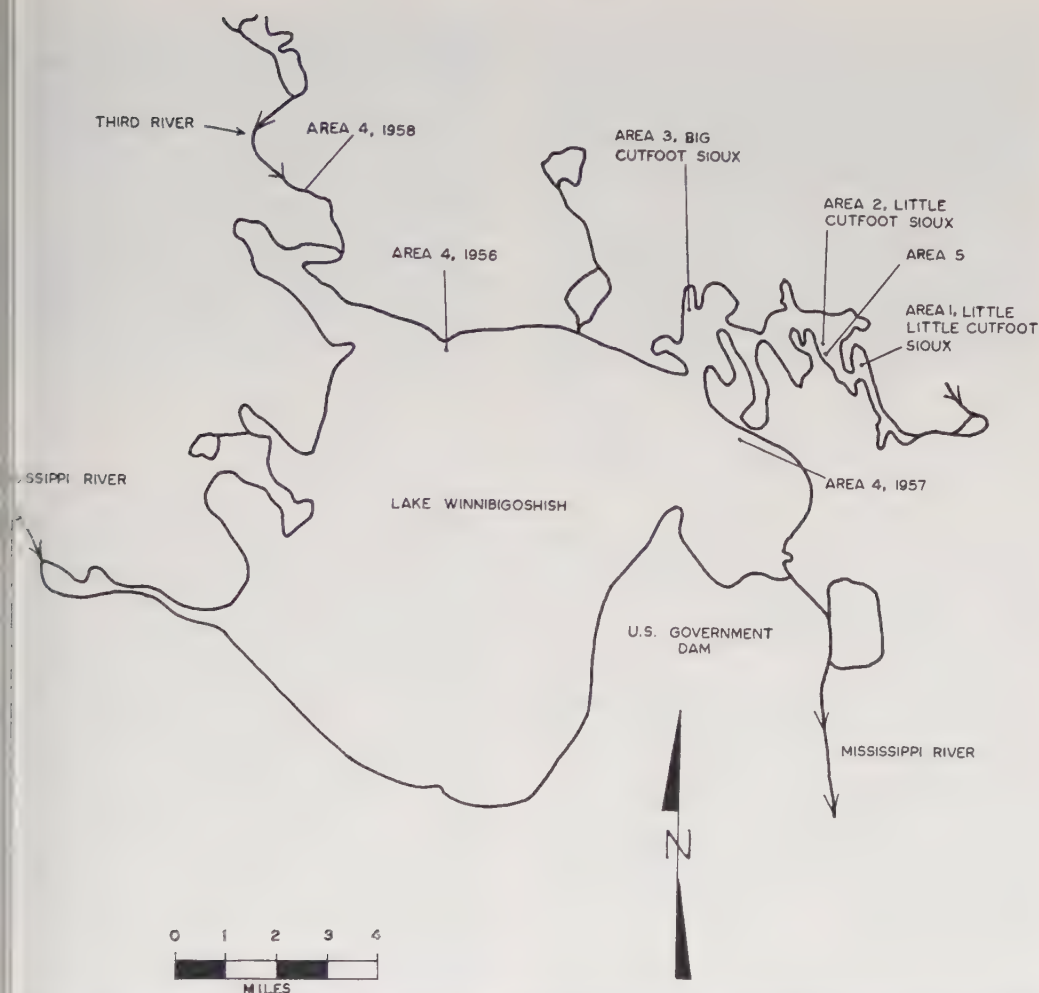


FIGURE 1. Lake Winnibigoshish and connected waters of north-central Minnesota, showing location of walleye spawning areas studied in 1956-59.

spawning walleyes observed on the shoals at night with the aid of a spotlight. The four study areas on which estimates of egg abundance were made were each 1,000 or 1,500 square feet. Egg collecting was done during April and early May and carried out through most of the incubation period.

Area 1 was 1,500 square feet of soft mucky bottom, overlain with some undecomposed remnants of aquatic plants and on which there was some growth of filamentous algae. Area 2 was located along the western and wave-washed shore of a cattail island in Little Cutfoot Sioux Lake (Figure 2). Area 3 was 1,000 square feet of firm, fine sand along the eastern shore of Little Cutfoot Sioux Lake where it was protected from the prevailing

wind (Figure 3). Gravel was deposited on this area in the fall of 1957 to form an experimental spawning area of coarser material (Figure 4). Area 3 was 1,000 square feet of gravel and rubble with occasional boulders located along the drop-off on a wave-washed shore of Big Cutfoot Sioux Lake (Figure 5). Area 4 was located along the north shore of Lake Winnibigoshish, and during the study period there were three study sites: (a) an area of gravel and rubble with occasional boulders studied in 1956; (b) an area of 1,500 square feet with a gradually sloping bottom of 60 percent gravel and 40 percent sand studied in 1957 (Figure 6); and (c) a gravel-rubble bar with occasional boulders in Third River, which was studied in 1958.



FIGURE 2.—Study Area 1, showing a shoreline and predominantly mucky bottom heavily utilized for walleye spawning during the study and on which egg survival to pre-hatching stage was 0.6, 4.5, 3.6, and 1.2 percent for the years studied.



FIGURE 4.—Bottom type on the improved portion of Area 2 as exposed by low water in May 1958. Rubble and gravel were deposited on the same bottom shown in Figure 3.

Area 5 in 1958 was a bar of firm, clean sand along the west shore of Little Cutfoot Sioux Lake. Water depths over these areas ranged from 6 to 40 inches during spawning and egg incubation (Table 1).

Sampling the bottom for eggs began soon after the major walleye spawning activity. Two sampling methods were used. Eggs were removed from 3- by 3-foot quadrats with a special sampler, or were taken with a hand net from randomly selected portions of the study areas. Eggs were collected throughout the incubation period, but special effort was made to estimate abundance shortly after the eggs were spawned and again at or near the eyed stage.

The box-like quadrat sampler was constructed of $\frac{1}{2}$ -inch iron rods welded to form a frame 3 feet square on the bottom and top and 4 feet deep. It was enclosed on the sides with window screen of 18 meshes to the inch. When

in use the sampler was placed with an open end on the lake bottom. The bottom was agitated and the eggs were collected by passing a 13- by 17-inch screen-covered rectangular hand net through the roiled water. The process was repeated until no more eggs were taken. On the coarse-textured bottoms it was necessary to remove larger stones before eggs could be collected. After sampling, the quadrat site was marked to prevent its being included in a future sample. Two or three quadrats were sampled in different parts of each study area to obtain each estimate of egg abundance. The total number of eggs on an area was estimated from the average number of eggs per square foot in the quadrats sampled.

The eggs were picked from the hand net with small forceps and examined with the unaided eye. Late in the incubation period samples of good eggs suspected of being p-eyed were also examined under a binocular



FIGURE 3.—Bottom type of predominantly sandy soil in unimproved portion of Area 2 as exposed by low water in May 1958.



FIGURE 5.—Gravel-rubble bottom of Area 3 as exposed by low water in May 1958.



FIGURE 6.—Sand-gravel bottom of Area 4 of 1957 exposed by low water in May 1958.

TABLE 1.—Physical characteristics and water temperatures of walleye spawning sites in Lake Winnebigoish and connected waters

Year	Bottom type	Water depth (inches)	Temperature (° F.)		
			Mini- mum	Maxi- mum	Daytime average
Area 1 (1,500 sq. ft.)					
1956	Muck-detritus	14-23	41	61	47
1957	Muck-detritus	20-36	46	58	53
1958	Muck-detritus	24-36	43	55	50
1959	Muck-detritus	24-40	45	63	51
Area 2 (1,000 sq. ft.)					
1956	Fine sand	14-23	41	59	47
1957	Fine sand	24-39	48	58	53
1958	Gravel-rubble	6-24	43	55	49
1959	Gravel-rubble	6-30	45	60	51
Area 3 (1,000 sq. ft.)					
1956	Gravel-rubble- boulder	14-26	43	56	52
1957	Gravel-rubble- boulder	14-26	47	64	55
Area 4 (1,500 sq. ft.—1957)					
1956	Gravel-rubble	12-30	—	—	—
1957	Gravel-sand	15-24	—	—	—
1958	Gravel-rubble- boulder	12-20	43	64	—
Area 5					
1958	Fine sand	12-24	43	55	49

roscope. "Pre-eyed" is defined as the stage of development when the eggs are eyed but the eyes are not visible without magnification. All eggs were counted, and dead and live eggs were tallied as they were collected. Live pre-eyed eggs are hyaline and turgid early in development but often are flaccid during the eyed stage, especially just before hatching. Dead eggs first show a small white speck (the dead embryo) and later become milky-white, yellowish, and completely opaque. In later stages of deterioration the eggs are often covered with fungus.

Random sampling was done at intervals of 2 to 4 days between the two estimates of egg abundance. The bottom was stirred vigorously with the foot and one quick pass of a hand net made through the roiled water. This operation was done on several locations in the study area, and sampling was continued until the ratio of live to dead eggs taken in a hand net remained constant.

In this study the number of eggs taken and the proportion of eyed and pre-eyed eggs are considered to be indices of fry production. In the Cutfoot Sioux hatchery there is little mortality between the eyed and fry stage. Schrader and Schrader (1922) noted that in this hatchery the death rate of walleye eggs increases rapidly and steadily until the fourth day of incubation after which mortality slows.

SURVIVAL OF WALLEYE EGGS DURING INCUBATION

Studies in 1956

It was estimated that 112,900 walleye eggs (5 per square foot) were spawned on the sticky soil of Area 1 in 1956. Shortly after spawning 74.8 percent of the eggs were alive and presumably represent fertilized eggs. The

percentage of live eggs decreased to 4.7 after 11 days. During this period the total number of eggs on the area decreased from 112,900 to 14,790, probably because the dead eggs disappeared. Three days later, at the pre-eyed and eyed stage, the number of dead eggs was further reduced (Table 2), but the number of live eggs remained fairly constant. The loss of dead eggs resulted in the apparent increase in percentage survival shown in Table 2. On the basis of data for the 11th day of observation probable fry production, computed from the number of eyed eggs, was estimated as 0.6 percent of the number of eggs laid. This survival was calculated from the 695 or 4.7 percent of 14,790 eggs estimated to be present at the eyed stage divided by the 112,900 eggs present at the beginning of incubation. The incubation period was 20 to 24 days at water temperatures between 41° and 61° F. with a daytime mean of 47° F.

The percentage of live eggs in the samples on the firm sand bottom of Area 2 declined from 90.8 shortly after spawning to 5.5 percent in the pre-eyed and eyed stage 14 days later. The decline in total number (Table 2) between May 8 and May 17 appears to have been caused by strong southeast winds (gusts up to 50 miles an hour) on the night of May 10. Apparently the undertow carried many eggs off the study area. Using the calculation method described for Area 1, survival of eggs

TABLE 2.—*Estimated abundance of walleye eggs on spawning areas of different types in Lake Winnibigoshish, Minnesota, and connected waters, together with survival of eggs during the incubation period and approximate days of incubation*

Item	Area 1				Area 2			
	1956	1957	1958	1959	1956	1957	1958	1959
Number eggs early in incubation ¹	112,900 (75)	41,550 (27)	—	—	93,220 (93)	25,515 (26)	—	654,000 (6)
Number eggs late in incubation ¹	14,790 (10)	6,080 (5)	—	115,780 (77)	46,000 (46)	5,890 (6)	—	1,040,000 (1,040)
Percentage live eggs following spawning	74.8	—	—	—	90.8	—	—	—
Early incubation	51.3	—	—	—	73.4	—	—	—
Mid-incubation	15.1	54.7	8.0	29.9	29.8	91.2	36.5	—
Late incubation	4.7	18.2	—	5.1	23.0	51.9	—	—
Eyed and pre-eyed	10.1	29.4	3.6	1.2	5.5	42.8	35.7	—
Percentage egg survival during incubation ²	0.6	4.5	3.6	1.2	2.7	9.9	35.7	—
Estimated fry production	695	1,880	—	1,390	2,530	2,530	—	269,000
Approximate incubation period (days)	20–24	12–14	16–21	16–18	20–24	12–14	16–21	12–16

Item	Area 3		Area 4		Area 5	
	1956	1957	1956	1957	1958	1959
Number eggs early in incubation ¹	6,400 (6)	—	—	—	—	—
Number eggs late in incubation ¹	25,925 (26)	5,130 (5)	—	9,735 (7)	—	—
Percentage live eggs following spawning	28.3	—	—	—	—	—
Early incubation	71.2	—	—	—	—	49.8
Mid-incubation	56.3	24.3	—	—	22.9	—
Late incubation	17.5	—	—	—	—	—
Eyed and pre-eyed	52.3	17.9	34.3	17.4	5.2	13.2
Percentage egg survival during incubation ²	17.5	17.9	34.3	17.4	5.2	13.2
Estimated fry production	4,525	925	—	1,655	—	—
Approximate incubation period (days)	14–16	12–16	—	—	18–21	16–21

¹ Number per square foot in parentheses.
² Obtained on Areas 1 and 2 in 1956 and 1957 by multiplying the minimum percentage of live eggs in the sample expressed as thousandths, by the last estimate of egg abundance, and dividing this product by the first estimate of egg abundance. The best estimate of percentage egg survival was the observed minimum on Areas 1 and 2, 1959; Area 1956 and 1957; and Area 4, 1957. In 1958 the estimated percentage of eggs which produced fry was the observed minimum survival in hand-net samples at the pre-eyed and eyed stage.

to fry is estimated at 2.7 percent. The incubation period was 20 to 24 days at a water temperature ranging from 41° to 59° F. with a daytime mean of 47° F.

In 1956 spawning first occurred on the

gravel-rubble-boulder bottom of Area 3 May 9, but most spawning took place on May 15 and 16. On May 14, 28.3 percent of the estimated 6,400 early-spawned eggs were alive. After the later spawning, however, 71.2 p

of an estimated 25,925 eggs were alive. Four days later egg survival had declined to a minimum of 17.5 percent, which is the estimated egg-to-fry survival. The incubation period was 14 to 16 days at water temperatures ranging from 43° to 56° F. with a daytime mean of 52° F.

In the gravel and rubble bottom of Area 4 along the north shore of Lake Winnibigoshish 34.3 percent of the eggs in one series of bottom samples taken near the end of the incubation period were alive. Actual survival was probably lower than indicated, however, because many dead eggs from the sampling area were found in filamentous algae cast up along the shore.

Studies in 1957

Water levels on the study areas were about 10 inches higher in 1957 than in 1956. Spawning occurred over the same areas but in deeper water. Fewer eggs were laid on Area 1 than in 1956 (27 compared to 75 per square foot). But 4 days after spawning the percentage of live eggs was 54.7. This declined to a minimum of 18.2 percent 5 days later. Estimated fry production was 4.5 percent of the eggs laid or about 2.7 times more than in 1956. Water temperatures averaged about 6° higher in 1957 than in 1956 (range 46° to 58° F. with a daytime mean of 53° F.). Dissolved oxygen was 10.4 p.p.m. and pH 7.8. The incubation period was 12 to 14 days or slightly less than half that of 1956.

On Area 2 there were less than one-third as many eggs in 1957 as in 1956, and at the end of the incubation stage 91.2 percent of the eggs were alive. Egg-to-fry survival was estimated at 20.9 percent, but this is probably minimal because it is likely that some live eggs washed out of the area. Minimal egg-to-fry survival on Area 2 was about 3.6 times better in 1957 than in 1956, and fry production was about the same in both years even though fewer eggs were spawned. Water temperatures were higher in 1957 than in 1956 (ranging from 43° to 58° F. with a daytime mean of 53° F.). The incubation was shorter (12 to 14 days). Dissolved oxygen was high and pH approximately neutral.

The abundance of eggs on Area 3 in 1957 was about one-fifth that of 1956 (5 eggs instead of 26 per square foot). Survival through the 12- to 16-day incubation period was estimated at 17.9 percent. Water temperatures, dissolved oxygen, and pH were similar to those for Areas 1 and 2.

Area 4 in 1957 had a gravel and sand bottom and was located along the north shore of Lake Winnibigoshish about 6 miles east of Area 4, 1956. Survival of eggs here in 1957 to the eyed stage was estimated at 17.4 percent with temperatures, oxygen, and pH similar to that for the other three areas.

Studies in 1958

Water levels in 1958 were more than 2 feet lower than those of 1956 and 1957. The areas previously studied in the Cutfoot Sioux lakes were dry except along their outer margins. Walleye spawning took place on bottoms formerly too deeply submerged to receive much use. Some of the gradually sloping bottom of Lake Winnibigoshish used in 1956 and 1957 for spawning was sparsely used or unavailable. Since most of the study areas were not in a condition comparable to that of previous years, no quadrat estimates of egg abundance and survival were made. Percentage survival of eggs to fry was estimated by periodic hand-net sampling.

Walleyes spawned in 1958 on mucky bottom in Area 1 similar to that used during the 2 preceding years. Proportion of live eggs midway through incubation was estimated at 8 percent, and the estimated percentage hatch was 3.6 percent. Water temperatures ranged from 43° to 55° F. with a daytime mean of 50° F. The incubation period was between 16 and 21 days. Gravel was added to Area 2 in the fall of 1957 to form an artificial spawning area, and the 1958 egg survival on this area will be considered separately. Eggs from Area 3 were collected once from a narrow zone of gravel along the shore during the early incubation period. Of these, 70 percent were alive. The rest of this spawning area was above water.

Area 4 in 1958 was located on gravel-rubble-boulder bottom in the lower portion of the Third River. The proportion of live eggs midway in incubation was estimated at 22.9 percent, and the percentage alive at the end of the 18- to 21-day incubation period was estimated at 5.2.

Area 5 was worked first in 1958 and was located on a fine sand bottom along the west shore of Little Cutfoot Sioux. Water temperatures ranged from 43° to 55° F. with a daytime mean of 49° F. Early in incubation the percentage of live eggs was 49.8. By the end of the incubation period (16 to 21 days) survival was estimated at 13.2 percent.

Studies in 1959

Water levels in 1959 were about 12 inches higher than in 1958, and it was again possible to make quantitative estimates on the original study areas. On Area 1, midway in the incubation period, 29.9 percent of the eggs were alive, but by the pre-eyed and eyed stage only 1.2 percent had survived. Water temperatures ranged from 45° to 63° F. with a daytime mean of 51° F. Incubation period was 16 to 18 days. Areas 3, 4, and 5 were not worked in 1959, and observations on Area 2 are mentioned in the following section.

SURVIVAL OF EGGS ON IMPROVED SPAWNING AREA

Observations in 1956 and 1957 indicated that egg survival was best on natural gravel bottoms. To test these observations experimentally, the natural sand bottom of Area 2 was covered with gravel and rubble in the fall of 1957. Twenty-five cubic yards of pit-run gravel screenings containing rocks from 1 to 6 inches in diameter were spread over the sand to form a layer approximately 6 inches thick (Figure 4). At the time this material was applied the water over it was 11 to 26 inches deep, but by the spring of 1958 only the outer edge of the area, along a drop-off, was submerged. Periodic random sampling with the hand net was done along this small submerged strip to determine the percentage survival of eggs. Here it was not unusual to pick up 300 to 400 eggs with a single pass of the hand net through the roiled water. The incubation period in 1958 was about 16 to 21 days with a water temperature range of 43° to 55° F. and an average daytime temperature of 49° F. Midway through incubation it was estimated that 36.5 percent of the eggs were alive, and at the pre-eyed and eyed stage survival was 35.7 percent. This survival rate was the highest found in the present series of observations and is three times that recorded for sand bottom at the same location in 1956 and 1957.

Water depths over the improved area in the spring of 1959 ranged from 6 to 30 inches, and eggs were deposited over the entire bottom during a 6- to 8-day period. It was estimated that 95.8 percent of the eggs were alive early in incubation and that there were about 655 eggs per square foot. Later, additional spawners used the area and at the pre-eyed and eyed stage there were 1,040 eggs per square foot. Survival of the eggs was esti-

mated to be 25.9 percent. Incubation period was 12 to 18 days at water temperatures ranging from 45° to 60° F. with a daytime mean of 51° F. Abundance of eggs on this improved area was more than 10 times that observed on the former sandy bottom, and estimated production was more than 100 times that observed in 1956 on the sand bottom (Table 1).

EGG SURVIVAL CURVES

When egg survival is plotted, curves of various shapes are formed (Figure 7). Initial percentage survival on the muck and detritus of Area 1 in 1956 was quite high followed by a steady decline through the mid-incubation period (Figure 7A). Toward the end of incubation the survival curve leveled off. At this time the number of dead eggs taken increased and caused an apparent increase in percentage survival rate for pre-eyed and eyed eggs. Actual egg survival, however, declined slightly.

The percentage viability of early spawned eggs was quite low on the gravel-rubble bottom of Area 3 in 1956 (Figure 7C). Percentage survival of live eggs increased, however, with the addition of eggs from later spawning. Survival then declined slowly but was more rapid just prior to pre-eyed and eyed stage. A decrease in abundance of dead eggs at this time again caused an apparent increase in percentage survival. The best estimate of real egg-to-egg survival therefore was that observed at the low point on the curve before the decrease in dead eggs.

Shorter incubation periods with faster development in 1957 resulted in more steeply sloped survival curves than those noted in 1956 (Figures 7B and 7D). Egg survival on Areas 1 and 2 was quite high in mid-incubation but decreased rapidly as embryo development progressed. On Area 1 the survival curve leveled off near the end of the incubation period, and a decrease in the number of dead eggs again caused an apparent increase in survival while real egg survival decreased slightly as it did in 1956. On Area 2 (Figure 7D) the difference between real and apparent survival was mostly because there was a decrease in the numbers of both live and dead eggs.

The observed tendency for dead wall eggs to disappear before the live eggs hatched was similar to that noted by Eschmeyer (1950) in Michigan lakes. These Minnesota observations indicate that estimates of wall egg survival through incubation should

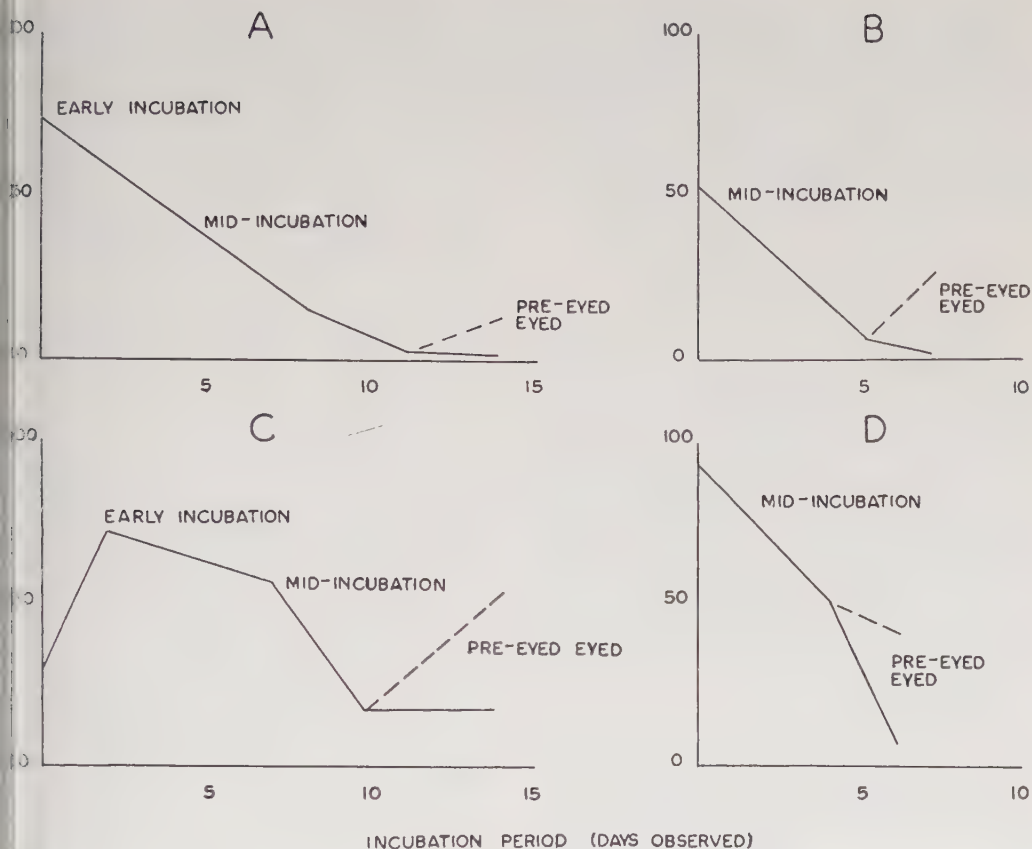


FIGURE 7.—Survival of walleye eggs during incubation to prehatching stage on three spawning areas of different soil types: A- Area 1, muck and detritus, 1956; B- Area 1, 1957; C- Area 3, gravel-rubble, 1956; D- Area 2, sand, 1957. Solid line shows estimated actual survival; broken line, apparent survival. Days of incubation are minimal since they are from the start of observation and may not include the entire incubation period.

led on survival and abundance data collected throughout all or most of the incubation period and that estimates based on single sporadic egg collections are apt to be in error.

FACTORS INFLUENCING EGG SURVIVAL

Bottom type

Egg survival was poorest on the soft muck-detritus bottom, was intermediate on firm, clean sand bottom, and was best on clean gravel-rubble bottom (Table 2). On the muck-detritus bottom of Area 1, egg survival ranged from 0.6 percent in 1956 to 4.5 percent in 1957 and averaged 2.4 percent for the 4 years considered. Survival on firm sand bottom ranged from 2.7 percent on Area 2 in 1956 to 13.2 percent on Area 5 in 1958 and averaged 8.6 percent for the 3 years. On the gravel-rubble bottom survival ranged from

17.5 percent on Area 3 in 1956 to 35.7 percent on improved bottom of Area 2 in 1958, and averaged (excluding Area 4 for 1956 and 1957) 25.0 percent; however, survival on similar gravelly stream bottoms in Third River was only 5.2 percent.

Superiority of gravel-rubble bottom over sand was further demonstrated on Area 2 where, after artificial addition of such a bottom, egg deposition increased at least 10 times; average percentage survival of eggs increased 5 times; and fry production increased more than 100 times. At the same time on Area 1, which was used as a control, there was no appreciable change from previous years (Table 2).

The physical and chemical factors responsible for differential egg survival on the several bottom types studied are undoubtedly quite

varied and their interactions complicated. The obvious physical differences between the bottom types are mainly in bottom firmness, amount of organic material, and particle size and shape. Eggs on clean firm gravel-rubble bottom were subject to less entanglement in debris and presumably less scouring from waves than on the other bottom types.

*Length of the incubation period
and water temperature*

The range of water temperatures on the bottom at the study areas was recorded with maximum-minimum thermometers (Table 1) and daytime water temperatures noted when the areas were sampled. Observations on maximum and minimum water temperatures and average daytime water temperatures during most of the incubation period do not lend themselves to critical analysis of the effect of water temperature on the rate of embryo development. It is apparent, however, that most rapid embryo development and short incubation periods were associated with high daytime water temperatures and high minimum water temperatures.

The incubation period for eggs on Areas 1 and 2 was about 20 to 24 days in 1956 and 12 to 14 days in 1957. Survival was highest here in the year with the shorter incubation period. The incubation period in 1956 and 1957 on Area 3 was about the same, and percentage survival was also about the same. Although there was also a decrease in egg abundance on Areas 1 and 2, a similar decrease in egg abundance occurred on Area 3 with little change in percentage of survival. During 1958 and 1959 incubation periods on Area 1 were intermediate (16 to 21 days), and percentage egg survival was intermediate between the low and high survival observed in 1956 and 1957. The other areas studied in 1958 and 1959 were either changed physically (Area 2) or observed for only 1 year (Areas 4 and 5) so no comparisons between years can be made. In summary, on Areas 1 and 2 long incubation periods were associated with poorer egg survival. Survival was best in years of warmer water and shorter incubation periods.

The adverse effect of cold weather on walleye spawning was noted by Derback (1947), and he indicated that a poor walleye hatch in Heming Lake, Manitoba, in 1947 was mostly due to a cessation of walleye spawning after the onset of cold weather. The cold weather lasted about a week, and after temperatures rose again, the run was not resumed. Wal-

eyes taken later in June were resorbing the eggs. Doan (1942) observed no relation between spring air temperature and subsequent size of walleye age classes in Lake Erie. Webster (1948) observed the effect of temperature changes on the survival and incubation of smallmouth bass (*Micropterus dolomieu*) eggs. Eggs at different developmental stages were collected from the lake at 60° F. and subjected to temperature changes in the laboratory. Changes ranging from 10° F. below to the original lake temperatures to 15° F. higher altered the length of the incubation period but did not affect egg survival.

Egg development and mortality

Developmental stage of dead eggs from Areas 1 and 2 was checked in 1956, 1957, 1958 and from Areas 3 and 4 in 1957. Opaque dead eggs were cleared in a saturated solution, but the condition of other dead eggs in an earlier stage of decomposition could not be observed directly. Most mortality occurred early in development. Eggs were considered to be infertile (Table 3) if they showed no sign of embryonic development after several days of incubation. Eggs classed as "opaque" had opaque shells and decomposed yolk. Initial fertility of dead eggs ranged from 0 percent on Area 2 in 1958 to 100 percent on Area 4 in 1957 and averaged 95.1 percent on all areas in all years. Representative samples containing both live and dead eggs from Areas 1, 2, 3, and 4 in 1957 showed an average initial fertility of 97.6 percent and a range from 96.4 to 100 percent. Since initial fertility was consistently high on the areas studied, it seems unlikely that inadequate fertilization of eggs was a significant factor in egg survival.

Wave action

Eschmeyer (1950) observed that in Lake Gogebic, Michigan, dead walleye eggs were sometimes moved considerable distances by waves and currents. He also noted an instance of recently deposited walleye eggs adhering to portions of rocks above the surface of the water and suggested that they had been washed into contact with the rocks during spawning. In large Minnesota walleye lakes windrows of eggs are sometimes seen along shores after spring storms.

Observations on the effect of high winds and waves were made on two occasions during the present study. Egg abundance declined from 93 to 46 eggs per square foot on Area

TABLE 3.—Initial fertility of dead walleye eggs collected in samples from spawning grounds in Lake Winnibigoshish and connected waters, Minnesota

Item	1956		1957				1958	
	Area 1	Area 2	Area 1	Area 2	Area 3	Area 4	Area 1	Area 2
Total dead eggs in sample	70	107	134	50	79	43	148	434
Number fertile	67	105	129	46	76	43	138	385
Percentage fertile	95.8	98.2	96.4	92.0	96.2	100	93.5	89.0
Number infertile	0	0	5	4	3	0	10	49
Percentage infertile	0	0	3.6	8.0	3.8	0	6.5	11.0
Number doubtful	3	2	0	0	0	0	0	0
Number fungused	26	10	0	0	0	0	0	0
Percentage fungused	37.2	9.3	0	0	0	0	0	0

After very strong winds during the night of May 10, 1956. Few eggs were observed on shore the following morning but most appeared to have been carried into deeper water where they were probably deposited on muck-clay bottom. The effects of wave action were again observed in 1956 on the north shore of Lake Winnibigoshish (Area 4 of 1956) where substantial numbers of dead walleye eggs were found entangled in clumps of filamentous algae. These had washed ashore during 3 days of moderate (15 to 25 m.p.h.) northerly winds. It could not be determined if the eggs were all dead before being washed ashore or if some live eggs were originally present. O'Donnell⁵ also noted that during a period of high winds an abundance of eggs containing large numbers of walleye eggs piled up on shore.

The effect of 2- to 3-foot waves on eggs on gravel bottom in Area 3 was observed directly (May 2, 1958). A total of 224 eggs (17 live, 67 dead) were collected in 1 hour on wavecrests and the backwash troughs between the breakers along shore. Most were from the backwash troughs, and none were noted on shore. It is probable that the effect of wave action varies with the size of lake, the amount and duration of wave action, and bottom type.

Use of spawning areas by other fish

Spawning white suckers (*Catostomus commersoni*) were observed on Area 3 in Big Lake Sioux in both 1956 and 1957. Groups of 5 to 10 fish swam along shore, moving in and out of the spawning shoals. They were feeding but appeared to be following a fish (presumably a female). Sucker eggs were collected on Area 3 along with incubat-

ing walleye eggs in both 1956 and 1957 and were usually found about 1 or 2 days after the walleyes spawned. Suckers also spawned on Area 4 of 1956 and Area 4 of 1958. Minnows (*Notropis* spp.) and the Johnny darter (*Etheostoma nigrum*) were observed in the study areas but were not abundant. Young yellow perch (*Perca flavescens*) were seen occasionally, particularly on Areas 1 and 2. On Area 1 perch eggs were often collected with walleye eggs.

Water levels, dissolved oxygen, and pH

Most walleye spawning took place in water of sufficient depth (12 to 30 inches) so that only a rapid and substantial drawdown could strand the incubating eggs. Abundance of eggs on all study areas was less in 1957 than in 1956 (Table 1). The higher water levels in 1957 may have made more spawning area available and thereby lessened the number of eggs spawned on the experimental areas. Low water levels in 1958 made former spawning areas, especially those along shores with gradual slopes, unavailable for spawning. The 1958 walleye year class appeared less abundant than usual in seine and trawl catches during the summer. The concentration of dissolved oxygen in water over the study areas in 1957 was high and pH normal for lakes in this area. Variation in dissolved oxygen and pH between areas was small. Fluctuations of water levels during the spawning period or dissolved oxygen and pH appear not to have been important factors in spawning success. Low water levels in 1958 may have been a factor in production of the weak 1958 year class.

SELECTION OF SPAWNING SITES

Eschmeyer (1950) reported that in two Michigan lakes spawning walleyes avoided

⁵ See footnote 3.

sand and utilized gravel areas only a few feet in diameter. Similar observations were made in Lakes Winnibigoshish and Big Cutfoot Sioux. Walleye eggs were found frequently on small isolated patches of firm gravel and rubble along extensive shorelines of pure sand where there was little or no spawning. Egg deposition on the improved spawning area in Little Cutfoot Sioux increased considerably over that noted on the previous sand bottom. Although it appears that walleyes select gravel bottom for spawning when it is available, spawning also takes place on less favorable bottom types when gravel is not present, and some fry are produced on such less favorable areas.

Walleye eggs were usually spawned where the water was between 12 and 30 inches deep, but in years of low water (1958 and 1959) numerous eggs were spawned on gravel in water as shallow as 2 inches. On Area 1 many eggs were found in water as deep as 40 inches. The deepest water from which walleye eggs were collected was approximately 48 inches. This collection was made off Area 2 following a severe windstorm, and it may be that these eggs were washed out to this depth.

EGG MORTALITY AND WALLEYE RECRUITMENT

Factors affecting development of year classes and recruitment of walleyes to the sport fishery in lakes like Winnibigoshish can be grouped by developmental stages of the fish as: (1) those affecting spawning and egg survival; (2) those affecting survival from the fry to fingerling stage; and (3) those operative between the end of the first year and the third and fourth year when the fish come into the catch. It has been previously demonstrated in a large Minnesota walleye lake, Mille Lacs (Maloney and Johnson, 1957), that in some years the crop of fingerlings nearly fails and that this failure is evident by midsummer. The cause of the failure may be either poor survival of eggs, fry, or advanced fry. In the previous study failure of the walleye fingerling crop was found to be coincident with the failure of the perch crop which the young walleyes use for forage. The

present study indicates, however, that mortality, especially as associated with unusually cold water during the incubation period, may also be an important factor in establishment of year classes. Although survival is greatly influenced by the nature of the bottom soil, survival of eggs in Lake Winnibigoshish is adequate to maintain a fishery in most years even though much of the bottom used for spawning is of an inferior type. Both the quality and extent of spawning areas must be considered in addition to factors that influence survival in later developmental stages.

ACKNOWLEDGMENTS

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Development of a System for Controlling Dissolved-Oxygen Content of Water

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ABSTRACT

A system for controlling the dissolved-oxygen content of a continuous flow of water was developed and tested. It is essentially a continuous flow of water through a partial vacuum. Two daily adjustments maintain the dissolved-oxygen content of the effluent water within 0.05 p.p.m. of the desired concentration. Minimum oxygen content of 0.5 p.p.m. and flow rates greater than 10 liters a minute were obtained. Modifications are suggested to improve the efficiency and capacity of this system. The behavior of four species of fish at reduced oxygen concentrations was observed. When the oxygen content was decreased below 3 p.p.m., ventilation rate and amplitude increased rapidly, activity decreased, normal colors faded, feeding ceased, and the fish became unresponsive to such stimuli as movement and vibration. Oxygen concentrations below 3 p.p.m. appear to be critical for these four species in resting conditions.

INTRODUCTION

The difficulty encountered in controlling dissolved oxygen in test water may be one reason for the scarcity of data on the effects of various oxygen concentrations on fishes. The test water should be renewed continuously in order to maintain uniform oxygen concentrations; remove waste products such as carbon dioxide, ammonia, and other nitrogenous wastes; and make possible rapid changes from one oxygen concentration to another.

Fry (1951) and Whitmore, Warren, and Goroff (1960) have employed systems based on the principle of bubbling nitrogen upward through a column of water. The dissolved oxygen diffuses into the bubble of nitrogen and is thus removed. Fry states that a volume of nitrogen is required to degas a volume of water. Such systems are relatively expensive, require considerable attention, and the volume of water which can be degassed is limited by the cost of nitrogen. Varying the temperature is not a satisfactory method for degassing because it may change the chemical characteristics of the water.

A system using a partial vacuum to degas water was developed and tested during the investigation reported here. It functioned very satisfactorily and produced water with uniform oxygen concentrations. Observations were made on four species of fishes maintained at reduced oxygen concentrations, using this system to furnish water of desired oxygen content. This method of degassing was simple and economical, and it can be applied to a wide variety of uses.

DESCRIPTION OF THE DEGASSING SYSTEM

The solubility of oxygen in water is dependent upon the temperature and partial pressure of oxygen. At a constant temperature the solubility is a linear function of the partial pressure. The system described herein depends upon a reduction in the partial pressure of oxygen effected by reduction of the total gaseous pressure. Basically, it is a continuous flow of water through a partial vacuum.

Figure 1 is a cutaway view of the system used. A heavy gauge 55-gallon drum, coated with epoxy resin to prevent rusting, is used as a degassing chamber. By running the vacuum pump continuously, the desired pressure can be maintained by opening the bleeder valve until equilibrium between the rate of pumping and rate of bleeding is reached. A selected pressure can be obtained in approximately 2 minutes. To allow for pressure changes during operation, it is necessary to vent the float. Water enters the drum through the float valve and is directed upward through a 1/8-inch hole. Being forced through a small hole, it strikes the top forcefully and disperses into fine droplets, thus increasing the rate of degassing.

The air, which is bled into the chamber and released through air stones, serves to keep the water well stirred and prevent oxygen stratification, to agitate the water and prevent supersaturation, and to aerate the incoming water if it is deficient in oxygen. The approximately 40 gallons of water in the tank serves as a buffer against changes in the rate or degree of degassing. In order to remove the water from the chamber when there is a high vacuum in the system, the water pump must be able

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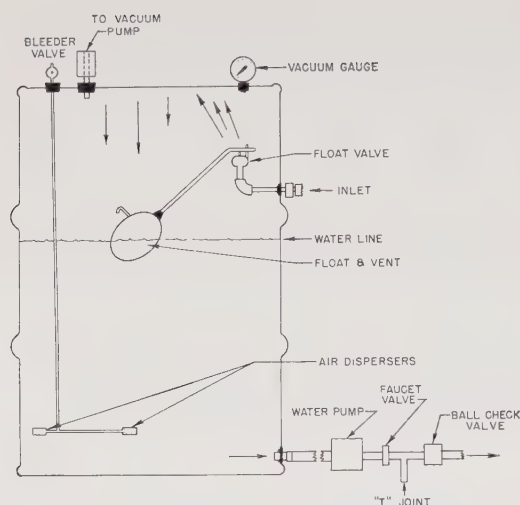


FIGURE 1.—Cutaway view of the degassing system.

to produce the minimum flow needed at a pressure of approximately 15 pounds per square inch. The "T" joint is used for back-flushing and priming the pump, and the check valve is necessary in case of power failure.

As described here, the vacuum pump has no provisions for removing condensed water vapor. As long as the chamber pressure is above 125 millimeters Hg, water vapor does not condense in the pump, but at higher vacuums it is necessary to change the oil daily. Vacuum pumps which do remove the condensed vapors from the oil are available commercially. If air-bleeding is eliminated, a higher vacuum, and therefore a lower oxygen concentration, can be obtained. This would be possible if a larger water pump with a by-pass line were used and degassed water instead of air were used to agitate the reservoir. Such a modification would have four very distinct advantages. (1) The amount of agitation would be more constant, regardless of vacuum maintained. (2) A higher vacuum could be obtained. (3) The continuous running of the pump would be unnecessary, since air-bleeding would no longer be needed. (4) The problem of water condensation in the pump oil would be lessened. A positive displacement water pump is preferable because its output varies less with a change in vacuum than that of a centrifugal pump, and its use would also eliminate air blocks as a source of trouble.

The system described above was operated continuously for 10 weeks during the summer of 1960 at Stone Laboratory, Put-In-Bay,

Ohio. Daily water temperature variation was 1° C. or less and did not materially affect the degassing process.

The effluent water did not vary by more than 0.05 p.p.m. from the desired concentration. Two adjustments daily were sufficient to maintain this accuracy. Within 2 minutes after a pressure had been set, the effluent water was within 0.1 p.p.m. of the desired level and within 5 to 8 minutes it reached the experimental level.

The capacity of this system, which is limited by the rate at which water could be pumped from the chamber, was not determined. The minimum oxygen concentration achieved was 0.5 p.p.m. at an output of 10 liters a minute, but at concentrations of 2 to 3 p.p.m. the pump would deliver as much as 10 liters per minute of degassed water with the same range of variation. Different flow rates did not affect the degree of degassing, indicating that higher rates could have been obtained.

EFFECTS OF REDUCED OXYGEN CONCENTRATION ON FISH BEHAVIOR

Methods

Water of controlled oxygen content from the system described above was conducted into six aquaria, five of which measured 30 by 51 centimeters and one 30 by 32 by 76 centimeters. The effluent water from each of these test chambers was run into a control chamber of the same size, where vigorous aeration restored the oxygen to 6–7 p.p.m. In order to retard oxygen exchange with the atmosphere and to prevent the fish from reaching the surface, polyethylene plastic covers were placed over all aquaria. The number of fish placed in each aquarium and the flow rate depended on the species and size of fish. Sufficient flow was maintained so that the fish did not reduce the oxygen content by more than 0.3 p.p.m. Turbulence caused by the flow prevented oxygen stratification. Fresh Lake Erie water (stored 12 hours or less) was used, and during the entire test period from June 20 to August 25, 1960, the water temperature stayed between 21° and 24° C.

Test specimens were caught on hook and line or were seined and were fed either platyfish or minnows before and during the test. With a few exceptions the fish were not held more than 3 days before testing, 2 days being allotted for acclimation in the test aquarium at air saturation of oxygen.

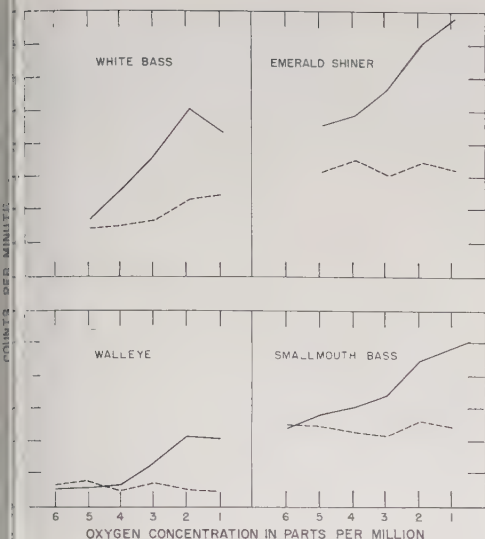


FIGURE 2.—Average ventilation rates of four species of fishes at various oxygen concentrations. Broken lines indicate control fish at oxygen concentrations between 6 and 7 p.p.m.

Water quality was determined by methods described by the American Public Health Association *et al.* (1949), using the unmodified Nessler method for dissolved-oxygen determinations. The pH, alkalinity, and free carbon dioxide were quite constant, averaging 8.2, 95 μ m., and 0.0 p.p.m., respectively. When the oxygen was less than 3 p.p.m., free carbon dioxide was measured daily in all test chambers. Measurements of oxygen were made in each test chamber four times daily at 4-hour intervals beginning at 8:00 a.m. Each species was tested at selected oxygen concentrations, beginning at either 6 or 5 p.p.m. Every 48 hours the oxygen was lowered 1 p.p.m. until a lethal concentration was reached. The maximum variation in oxygen content for the six chambers during a 48-hour period was 0.3 μ m., with extreme variations of 0.2 and 0.6 μ m.

The test and control aquaria were located against a wall in a room well lighted by natural illumination. All observations except circular rates were made from a distance of at least 10 feet, with comparisons of test and control fish being used to ascertain differences attributable to oxygen concentrations. As far as possible the fish in any pair of test and control chambers were of the same size. Circular rates and activity index counts were made each time the oxygen was measured. Rectangles, 13 by 25 centimeters, were

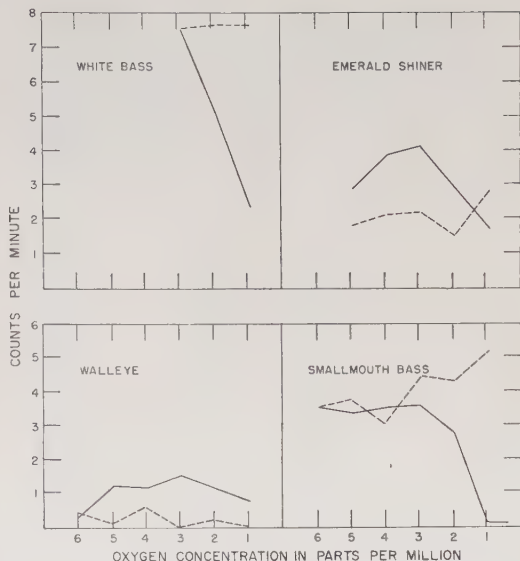


FIGURE 3.—Average activity index counts of four species of fishes at various oxygen concentrations. Index counts represent the number of times a minute that a fish's eye crossed a grid line. Broken lines indicate control fish at oxygen concentrations between 6 and 7 p.p.m.

drawn on the sides of the aquaria, and the activity index counts were recorded as the number of times a minute the fish's eye moved from one rectangle to another. Daily feeding behavior and food consumption were recorded also.

When the oxygen concentration was high, emerald shiners and walleyes occasionally used only one operculum in breathing. Some adjustment of the rate was therefore necessary when the counts were being averaged. At the time each count was made, the use of either one or two opercula was recorded, and when only one had been used, the count was multiplied by 0.75 before the averages were computed. This factor was selected because it brought the rate into agreement with other counts on the same fish when it was using both opercula.

Results

Ventilation rates were plotted against oxygen concentration (Figure 2) for white bass (*Roccus chrysops*), emerald shiner (*Notropis atherinoides*), walleye (*Stizostedion vitreum vitreum*), and smallmouth bass (*Micropterus dolomieu*). Ventilation rates are used as an index to oxygen stress and show a close relationship with oxygen concentrations. The activity index counts are plotted against oxygen

TABLE 1.—*Oxygen concentrations (p.p.m.) lethal to four species of fish*

Species	Sex	Weight (grams)	Lethal oxygen concentration (p.p.m.)	Survival at lethal concentration (hours)
White bass	Male	197	1	6.25
	Male	112	1	7.00
	Female	81	2	35.00
	Female	71	1	7.75
	Male	68	1	4.00
	Female	68	1	6.50
	Female	67	1	8.00
	Male	61	1	5.50
Emerald shiner	Female	48	1	1.75
	Female	10.9	1	5.75
	Female	4.7	1	6.00
	Male	4.4	1	10.00
	Male	2.5	1	9.00
Walleye	Female	2.5	1	8.50
	Male	254	1	11.75
	Male	190	1	11.00
	Female	187	2	34.00
Smallmouth bass	Female	176	1	9.00
	Female	406	1	18.25
	Female	284	1	26.00
	Male	145	0.5	6.00
	Female	82	0.5	5.50
	Juvenile	11	0.5	3.50
	Juvenile	6.8	0.5	3.75

concentration in Figure 3. There was a pronounced decrease in activity at oxygen contents below 3 p.p.m. Through general observations, as well as through the index counts, decreased activity was noted. The survival times at the lethal concentrations are listed in Table 1. As shown in the table, the smallmouth bass were more tolerant of low oxygen concentrations than the other three species. The smallmouth showed no more distress at 1 p.p.m. than the white bass did at 2 p.p.m. of oxygen. The latter probably would have died at 2 p.p.m. had that concentration been maintained for an additional 24 hours. Of the four species the white bass showed the greatest distress at 2 p.p.m.

Discussion

Ventilation rates consistently rose as the oxygen content was lowered, except immediately before death when they usually declined slightly. There was an accompanying increase in the amplitude of ventilation, a response most obvious among the walleyes and smallmouth bass. The effect of greater amplitude is probably as important as the rate in these two species. White bass showed very little increase in amplitude.

Lessened activity in low dissolved oxygen was most pronounced in the more active spe-

cies. The walleyes were very inactive at high oxygen concentrations, and the small change in activity that accompanied lowering of the oxygen concentration, as shown in Figure 3, was a result of surfacing behavior in response to oxygen stress. As the oxygen concentration was lowered, all four species became more lethargic, and at concentrations that subsequently proved to be lethal, the fish did not respond to external movement and vibration for periods as long as 2 days.

During the 48 hours that the oxygen concentration was 2 p.p.m., the white bass and lake emerald shiners ceased feeding. The smallmouth fed normally at this concentration but stopped feeding immediately when the dissolved oxygen was lowered to 1 p.p.m. Except on a few occasions, the walleyes refused to feed in either the test chambers or the holding tanks.

The most significant effect of low oxygen concentrations, judged on the basis of general observations and on the data described, was the marked change in behavior and appearance when the oxygen was reduced below 3 p.p.m. Below this concentration, ventilation rate and amplitude increased rapidly, activity decreased, normal colors faded, feeding ceased (except in smallmouth bass), and the fish became less responsive to stimuli. In addition, most of the fish remained in the upper half of the aquaria. Such behavior indicates that oxygen concentrations below 3 p.p.m. are probably critical for these species under the test conditions described here. Activity and the presence of toxic materials probably would raise the critical concentration substantially.

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SHORT PAPERS AND NOTES

Behavior of Splake and Brook Trout Fingerlings

Vincent (1960) reported on the behavior of a hatchery and wild strain of brook trout subjected to various environmental choices or stresses. The domesticated fish showed responses that might be detrimental to survival in the wild. The present study reports on comparative observations of the same strain of domestic brook trout (*Salvelinus fontinalis*) and the splake (*Salvelinus fontinalis* x *Salvelinus namaycush*) or hybrid resulting from crossing a male brook trout with a lake trout female. The procedures used in this work are essentially the same as those used by Vincent.

In this particular cross the parent stock consisted of the same strain of domestic brook trout used by Vincent and wild lake trout from Cayuga Lake, New York. Although the lake trout population in Cayuga Lake is essentially of hatchery origin, the parent stock from Seneca Lake is wild (Webster, Bentley, and Galligan, 1959). The fingerlings used in this study were reared under similar conditions in the Cornell University Experimental Fish Hatchery. Over the period of time that the observations were made (winter and early spring, 1960), the brook trout ranged in mean length from 14.5 to 35.0 millimeters and the splake from 20.5 to 45.0 millimeters.

HIDING REACTION

Behavior in the hatchery troughs was decidedly different between the two groups. The brook trout were spread evenly throughout the trough while the splake remained at the bottom and huddled along the edges and in the corners. Vincent (1960) tested this reaction by placing brook trout in a small aquarium (12 by 6 by 9 inches) with rocks for shelter. The domestic fish showed no tendency to hide regardless of the number of times he placed them in the tank. Wild-strain brook trout immediately took shelter.

To test this reaction in the present project, two small aquaria were set up and two-thirds of their floor area was covered with rocks. Fifteen fish from each group were introduced into separate aquaria. In none of the eight trials carried out over a period of 5 weeks in March and April did more than one or two brook trout go under the rocks when they

were placed in the tank. The reaction of the splake, however, was reversed. When fish were placed in the water, almost all of them immediately took shelter and only an occasional fish swam about.

These tests were repeated in darkness using the same aquaria and the same number of fish. Splake and brook trout were introduced into separate tanks and the lights turned on. After 10 minutes the lights were turned off. Before they moved, the position of each fish was rated. The side of the glass was then tapped and the fish again counted. Under the cover of darkness the splake did not hide under the rock but did stay near the bottom. The splake remained in this position until the sides of the aquaria were tapped, after which they took shelter. The brook trout were not affected by tapping and at all times occupied the entire tank.

In six separate trials only 12 splake were located beneath the rocks under the cover of darkness, but after the glass was tapped, 81 of the 90 splake sought shelter. With the brook trout the number under the rocks in darkness was seven, while after tapping eight of the brook trout were under the rocks.

VERTICAL DISTRIBUTION

Vincent (1960) reported that brook trout of the domestic strain exhibited a definite preference for the surface although the wild fish did not. In the present experiments the brook trout occupied the entire hatchery trough while splake remained on the bottom. To investigate this reaction, fish were placed in a tall glass tank measuring 36 by 6 by 6 inches. Water was homothermous and at the temperature to which the fish were acclimated. The tank was divided into four regions. From top to bottom they were region I, 0-4 inches; region II, 4-18 inches; region III, 18-32 inches; and region IV, 32-36 inches. Ten fish were placed in the tank and after 15 minutes had elapsed, the number in each region was tabulated. On two occasions fish were left in the tank for 45 minutes and the distribution did not essentially differ from that of 15 minutes. When placed in the tank, the splake immediately dived to the bottom and remained there with little movement while the brook trout swam throughout the area with definite preference for the surface region.

Each of the six trials over a period of 3 weeks showed similar results. Twenty splake and 20 brook trout were used in each trial. The total distribution of the 240 fish after 15 minutes was:

Depth (inches)	Number of brook trout	Number of splake
0-4	45	0
4-18	45	16
18-32	20	42
32-36	10	62

LIGHT AND DEPTH DISTRIBUTION

Trials were run in darkness to test the effect of light on depth distribution. The brook trout were concentrated in the upper half of the tank, but when a light was focused on the bottom of the tank with the brook trout, they immediately swam to the bottom and remained in the lighted region. Numerous trials showed no deviation in this response. Splake, on the other hand, were located in the lower half of the tank and when the light was shown at the base of the tank, attempted to swim through the bottom of the tank in what appeared to be an attempt to escape the light. This reaction normally would bring them into darker regions although in this case movement to the surface would have accomplished the same result.

This attraction for strong light is at variance with other observations on brook trout. Sivan and Fisher (1954) showed that brook trout preferred subdued rather than bright light. Hoar (1942) reports that trout were more active in the hours of darkness and also preferred full sunlight.

DISCUSSION AND CONCLUSIONS

In these observations domesticated trout behaved exactly as in previous tests carried out by Vincent (1960). Splake, however, showed a contrasting behavior in all trials attempted. In this respect they resembled the wild brook trout observed by Vincent in having a well-developed hiding reaction, a tendency to seek depths, and negative phototaxis. The latter trait is characteristic of young lake trout reared in New York hatcheries. It is concluded that the responses of this domesticated stock of brook trout relative to light traits were not transferred to the F₁ hybrid.

Webster, D. A., personal communication.

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Destruction of Salmon Larvae by *Hydra oligactis*¹

During experiments on viability of eggs of chinook (*Oncorhynchus tshawytscha*) and silver (*O. kisutch*) salmon, heavy mortality at the time of hatching was noted in trough compartments nearest the water inlet. Close inspection revealed that large numbers of hydras were present in these compartments. An effort was made, therefore, to determine the species of hydras, the developmental stages at which the salmon were affected, the effect of varied exposure time to a large number of hydras, and the effect of different densities of hydras.

Gudger (1927, 1934) states that certain coelenterates are enemies of fishes. He found that hydras and the polyps of *Aurelia* and *Clytia* kill young fishes and, if these are small enough, engulf them. Gudger also notes that *Polypodium* in its larval stolon stage para-

¹ Contribution Number 118, College of Fisheries, University of Washington, Seattle, Washington.

TABLE 1.—Mortality in groups of chinook salmon eggs and resultant larvae incubated at various distances from the inlet water

Distance from inlet (centimeters)	Number of eggs	Number hatching (days 43–45)	Survivors to feeding stage (day 97)		Fish pairs
			Number	Percentage	
140	200	97	0	0.0	A
220	197	100	89	45.2	A
300	202	96	87	43.1	A
380	195	97	93	47.7	A
100	200	199	0	0.0	B
180	186	186	173	93.0	B
260	209	203	202	96.7	B
340	206	203	200	97.1	B

sitizes the eggs of Volga sturgeon, and two colonial hydroids of the genus *Hydrichthys* parasitize fishes. Hickson (1925) suggests that hydras may destroy but not ingest frog tadpoles. Lynch² reports that hydras can kill but not devour adult fairy shrimp (*Eubranchipus oregonensis*). Schuberg (1905) indicates that *Hydra fusca*³ can injure trout 30–40 millimeters long, as evidenced by the presence of nematocysts in the fin epithelium of recently dead trout. Cordero (1941) notes that teleost larvae of *Prochilodus*, *Trachycorystes*, and *Arapaima* were damaged in the mouth region by *Hydra iheringi*.³ Larvae about 10 millimeters long were most seriously affected, but no deaths were reported. Destruction of trout fry held in the anterior portion of hatchery troughs was observed by Beardsley (1904). Inspection of these troughs showed that *Hydra pallida*,³ presumably introduced into the system with the water, were present. On the basis of experimental evidence Beardsley concluded that the hydras caused the unusual mortality of trout fry.

METHODS AND MATERIALS

Hydras were collected periodically at several locations throughout the University of Washington experimental hatchery. Of the 50 hydrozoans examined, all were *Hydra oligactis*. Lengthwise looping of the thread in unexploded nematocysts (holotrichous isorhizas) is considered to be an exclusive trait of this species and was observed in every hydra examined. *H. oligactis*, one of the largest hydras, reaches a total length of 5–6 centi-

meters when fully elongated but can contract to less than 2 millimeters when disturbed. The speed and degree of contraction are probably major reasons why the animals are inconspicuous to hatchery workers.

For the first experiment, sublots of fertilized eggs from two pairs of chinook salmon (pairs A and B) were distributed among cement troughs at various distances from the inlet (Table 1). The unfiltered water came directly from Lake Washington. Perforated steel plates at 40-centimeter intervals divided each trough into eight compartments. Within 10 days large numbers of hydras were present in the two anteriormost compartments, but relatively few could progress past the steel baffles at the end of the second compartment. Infested compartments contained hydras which adhered to the eggs as well as the sides and bottom of the trough. Percentage survival of eggs from the time of fertilization until they began to feed was recorded.

In a second experiment two groups of chinook salmon larvae, hatched 6 days previously, were placed in 1-liter beakers half-filled with lake water. One beaker contained 400 *H. oligactis* while the other served as control. At the end of 5 minutes the fish were removed to running lake water and observed for 8 days.

Since recently hatched larvae of chinook salmon were no longer available, the final experiment involved silver salmon of a common parentage that had hatched 3 days previously. Groups of five larvae were placed in duplicate 1-liter beakers containing 0, 1, 20, 50, or 100 hydras, and two beakers containing 500 milliliters of lake water in which 400 *H. oligactis* had been confined for 24 hours. The beakers were placed in a flowing lake-water bath and aerated. During the balance of the 33-day experiment, mortalities were recorded and dead fish removed daily.

² Dr. James E. Lynch, University of Washington, College of Fisheries, Seattle, Washington (personal communication).
³ Ewer (1948) states that *Hydra pallida* and *H. fusca* are synonyms of *H. oligactis*; moreover, he considers the taxonomic description of *H. iheringi* inadequate for valid identification.

TABLE 2.—Cumulative mortality of chinook salmon larvae held in 500 milliliters water and exposed to 400 *H. oligactis* for 5 minutes

[Sample size = 10]

Day	Hydra group	Control group
1	1	0
2	4	0
3	6	0
4	7	0
5	8	0
8 (final)	8	0

EXPERIMENTAL RESULTS

The effects of *H. oligactis* on chinook salmon eggs and resultant larvae are presented in Table 1. Chi-square tests indicate that among the eggs from any pair of fish, the same number of eggs hatched in each compartment regardless of the distance from the hydra. This survival suggests that embryonic stages of chinook salmon are unaffected by the presence of these hydrozoans. It was noted that during the hatching processes the embryos rotated within the egg membrane so vigorously that all extraneous matter such as hydra and hydras were eliminated from the egg space. Larvae confined to compartments heavily infested with *Hydra*, however, suffered 100 percent mortality within 6 days after hatching. These larvae displayed several small whitish areas on the yolk-sac which coalesced shortly before death. Comparatively little mortality was evident among survivors of remaining groups between hatching and yolk-sac absorption (day 97) despite the abundance of hydras throughout all compartments by day 68 (Table 1). This survival indicates that late larval stages are resistant to the effects of *H. oligactis*.

The results of the second experiment (Table 2) strongly suggest that chinook salmon larvae need only short contact with *H. oligactis* for death to occur. During the 5-minute period larvae were exposed to the hydras the salmon displayed violent convulsive movements, while the control group exhibited little movement. As was evident in the previous experiment, afflicted larvae displayed the characteristic symptoms of "white spot disease." This (1956) describes the etiology of white spot disease and indicates that a variety of chemical or physical phenomena can produce this syndrome.

The effects of graded densities of *H. oligactis* on silver salmon larvae are summarized in

TABLE 3.—Cumulative mortality of silver salmon larvae held in 500 milliliters water and exposed to different densities of *H. oligactis* for 33 days

[Pooled sample size = 10]

Hydras per beaker	Days									
	1	2	3	4	5	6	19	26	33 (final)	
0 (Control)	0	0	0	0	0	0	0	0	0	
1	1	1	1	1	1	1	1	1	1	
20	2	5	7	8	9	9	9	10	10	
50	1	5	5	5	5	5	5	6	6	
100	5	5	6	6	7	7	7	7	8	
0 ("effluent" from 400 <i>H. oligactis</i>)	0	1	2	2	2	2	2	3	3	

Table 3. Heavy mortality occurred in beakers containing 20 or more hydrozoans. Affected larvae displayed defects typical of white spot disease. Approximately 20 percent of the hydras placed in the 50- and 100-hydra beakers died by the end of the 33rd day, perhaps of starvation. Of the larvae confined to the "effluent" from 400 *H. oligactis*, three died but none displayed small whitish areas on the yolk-sac. Although these data do not definitely indicate that a toxic substance is liberated by *H. oligactis*, further experimentation may reveal the existence of a toxin.

An effective method of controlling hydras in the presence of young fish has been noted by Bastos (1950), who found that a salt (NaCl) bath of about 3,000 p.p.m. will eliminate *Hydra iheringi*⁴ without harm to *Astrototus*, *Prochilodus*, and *Plagioscion*. No tested method of eliminating *Hydra* spp. in the presence of developing salmon eggs is currently available. On the basis of the present study it is suggested that salmon eggs incubated in troughs infested with hydras be transferred to clean receptacles several days prior to hatching.

SUMMARY

Recently hatched larvae of Pacific salmon were exposed to *Hydra oligactis* for varying lengths of time. Many of the fish exhibited symptoms characteristic of "white spot disease" and usually died within 5 days. Fish were affected adversely by exposures as short as 5 minutes. Increasing abundance of the hydrozoan results in increasing mortality of newly hatched salmon. Fish which had not hatched, and those which had reached later larval stages were apparently unaffected by the presence of these coelenterates.

⁴ See footnote 3.

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Disappearance of Endrin from Fish and Other Materials of a Pond Environment

A fish-kill occurred in a pond located in Weld County, Colorado, in the summer of 1959 after it had received endrin from the aerial application of the toxicant to a nearby beet field. Analyses of the water, mud, aquatic vegetation, and tissues of surviving fish from the pond revealed a relatively rapid disappearance of endrin residues. Observations incident to the residue study suggest that the acute toxicity of endrin in this field situation is not as great as might be expected on the basis of previous laboratory studies (Iyatomi *et al.*, 1958; Henderson, Pickering, and Tarzwell, 1959).

A beet field located adjacent to the study pond was treated with endrin at the rate of 6 ounces of active ingredient per acre on June 21, 1959. An emulsifiable concentrate con-

taining 19.5 percent active ingredient was applied by airplane with water as the carry agent. The pond leasee noted a number dead and dying fish on June 24. On June 25 large numbers of dead yellow perch (*Perca flavescens*), pumpkinseed (*Lepomis gibbosus*), bluegill (*Lepomis macrochirus*), black crappie (*Pomoxis nigromaculatus*), largemouth bass (*Micropterus salmoides*), and carp (*Cyprinus carpio*) were observed by representatives of the Colorado Department of Game and Fish.

State personnel collected water samples on June 25 and June 28 and sent them to the Fish-Pesticide Research Laboratory, Bureau of Sport Fisheries and Wildlife, Denver, Colorado, for analysis. Published results from laboratory studies indicated endrin was extremely toxic to fish, and since very little was known of the fate of endrin in the aquatic environment, an effort was made to obtain information on the persistence of this toxicant. A replicated study was not conducted and results presented here are not conclusive, but they indicate general trends and what might be expected under similar conditions.

The study pond, located near Mead in Weld County, Colorado, is approximately 4 acres in surface area, with a maximum depth of 4 feet and an average depth of 3 feet. The bottom is composed of soft mud. At the time of the endrin spray, the water was very clear and the pond contained a dense growth of aquatic vegetation composed mainly of *Utricularia* and *Ceratophyllum* sp. This condition remained until late fall. The pH of the water was 9.1, phenolphthalein alkalinity 35 p.p.m. and total alkalinity 147 p.p.m. Afternoon water temperatures in the summer averaged about 75° F.

Samples of fish, vegetation, mud, and water were collected and preserved for chemical analysis in accordance with the methods outlined by Cope (1960). All samples of fish and mud were taken from the northwest portion of the pond near the shore. It is believed that the plane flew over this section of the pond during the endrin spray application to the adjacent beet field. Most of the water and vegetation samples were obtained from the same area, but on two occasions they were also collected from the middle of the pond. Chemical analyses for endrin residues in the materials were made by paper chromatography.

Live-cars, containing fathead minnows (*Mephales promelas*), black bullheads (*Ictalurus melas*), and green sunfish (*Lepomis*

TABLE 1.—Endrin residues in the water, mud, and vegetation of a pond after contamination by aerial spray—expressed as parts per million

Date, 1959	Water ¹	Mud	Vegetation
July 25	0.04	—	—
July 28	0.01	—	—
July 7 ²			
Northwest	0.01	0.17	0.25
Middle	0.01	—	0.55
July 16	0.004	0.06	0.30
July 24 ²			
Northwest	0.00	—	0.07
Middle	0.00	—	0.07
August 4	0.00	0.16	0.37
August 13	—	0.80	0.00
August 21	—	0.35	0.00
September 4	—	0.00	—
September 21	—	0.00	—

¹ Composite samples—surface and subsurface.

² Samples of water and vegetation collected from both middle and northwest sections of the pond on these dates; on all other dates samples collected from the northwest section only.

Utricularia) from a commercial hatchery, were placed in the pond on July 23 to assess the residual toxic effects of endrin. The live-cars were removed on July 27, and the fish prepared for chemical analysis.

DISAPPEARANCE OF ENDRIN RESIDUES

The results of the chemical analyses of water, mud, and aquatic vegetation are presented in Table 1. The values for vegetation represent the residues found in composite samples of *Utricularia* and *Ceratophyllum*. Separate analyses revealed there was no appreciable difference between the two species (the amounts of endrin contained on July 7). Endrin disappeared from the water about 1 month after the original contamination of the pond. None was found in the vegetation after August 4, but it remained in the mud for 2 months after the spray. Appreciable amounts of endrin were found in the fish about 2 months after the spray, but in less than 3 months no measurable quantities were detected (Table 2).

The results of the analyses of mud, vegetation, and fish do not present a logical series in that a steady build-up or decline of endrin is undiscernible. Sampling error, lack of replication, and differences in fish species probably account for this lack of trend. Although samples of mud, water, and vegetation were replicated, the results establish approximate dates for the disappearance of endrin in the pond. Data from fish samples suggest a general decline in residues starting about 2 months after the spray. Results from the analyses of pumpkinseed samples are probably indicative of endrin residues present in the

TABLE 2.—Endrin residues in the fish of a pond after contamination by aerial spray

Date, 1959	Number of fish per sample	Average endrin concentration (p.p.m.)	Species of fish
July 27	3	Tr ¹	Fathead minnow ²
July 27	1	0.30	Black bullhead ²
July 27	2	0.60	Green sunfish ²
July 27	4	0.14	Bluegill
August 17	1	1.00	Bluegill
August 17	3	0.58	Pumpkinseed
August 21	4	0.05	Black crappie
September 4	5	0.02	Black crappie
September 4	3	Tr - N ³	Pumpkinseed
September 21	3	Tr - N ³	Pumpkinseed
October 13	2	Tr - N ³	Pumpkinseed

¹ Trace—amounts too small to measure.

² Fish from 4-day live-car exposure.

³ Values for individual fish range from a trace to none detected.

general fish population and in the centrarchid population in particular.

BIOASSAY FISH

The fish held in live-cars to determine possible toxic effects of residual endrin suffered no mortality during the 4-day exposure period, but they did accumulate endrin (Table 2). They were placed in the pond on July 23. On July 24 no detectable endrin was present in the water. The question arises as to how the fish obtained endrin when it was apparently absent from the water for at least 3 days and possibly all 4 days of the exposure period. Fish may have received the toxicant in at least two ways. The aquatic vegetation and the mud still contained endrin, and the bottoms of the live-cars were embedded in 3 to 4 inches of mud and vegetation. In addition, the live-cars were placed near shore, and on the day that they were removed a strong wind was blowing and turbid water was noted in the area where the live-cars were located. The suspended material in the water and the close proximity of the mud may have offered the fish opportunity to obtain endrin through the leaching of endrin from these materials and the ingestion of water containing suspended matter. The fish could also have obtained some endrin from feeding on small aquatic organisms that probably contained the toxicant. It is known from our work with forest-insect sprays that fish can concentrate DDT in their tissues by feeding on aquatic insects that have been exposed to small amounts of DDT for 3 to 6 hours. Trout, feeding on these insects, concentrated measurable amounts of DDT in less than 24 hours (unpublished data).

ACUTE TOXICITY OF ENDRIN

Although large numbers of fish were killed by endrin, a substantial part of the population survived. The clarity of the water permitted unobstructed visual observations, and on every occasion that samples were collected, large numbers of live fish were seen. Anglers caught fish from the pond less than 1 month after the spray and considerable numbers of bluegill, pumpkinseed, and black crappie were taken in small hardware-cloth traps. Large-mouth bass were not caught in the traps but could usually be seen swimming about in seemingly good condition. Henderson *et al.* (1959) stated that endrin was the most toxic chemical that had been tested in their laboratory. The 96-hour TL_m values for bluegill, fathead minnow, goldfish (*Carassius auratus*), and guppy (*Lebistes reticulatus*) ranged from 0.66 p.p.b. (parts per billion) for bluegill to 2.1 p.p.b. for goldfish. Four days after the pond was subjected to the spray, 40 p.p.b. of endrin was found in the water. After the initial kill, no dead or dying fish were observed in the pond. The acute toxicity of endrin appears to be less under these field conditions than in the laboratory.

Poor distribution of the toxicant in the pond might account for the large number of live fish during the first few days after the pond was contaminated. The pond, however, is well-exposed and wind action facilitated mixing over a period of time. On July 7, 16 days after the spray, substantial amounts of endrin (10 p.p.b.) were found in both the middle and northwest portions of the pond, and fish observed at the time did not exhibit any indications of poisoning. Henderson *et al.* (1959), considering the possible effects of pH, alkalinity, and hardness, found no significant differences in toxicity that could be ascribed to these features of water quality within the ranges tested. The highest pH they tested was 8.2, while the pH of the study pond was 9.1. This unusually high pH in the pond could be a factor, and it is also possible that some unknown characteristic or combination of characteristics of water quality could account for the apparent low toxicity of endrin in this particular field situation.

Although the present study was limited in scope and the results may not have universal application, it established the approximate length of time that endrin remained in the mud, water, fish, and aquatic vegetation under one set of field conditions and, under

the same conditions, permitted qualitative observations of the acute toxicity of endrin to fish.

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Growth of Largemouth Bass Fry at Various Temperatures

The largemouth bass, *Micropterus salmoides* (Lacépède), is one of the most important game fishes over much of the United States. Its large size accounts for much of its popularity. Largemouth bass increase in maximum size from the northern to southern part of the range with the largest fish occurring in Florida. *Field and Stream* recognized this size variation and divided its annual fishing contest for largemouth bass into three divisions: Florida, southern, and northern. This north-south cline in maximum size could be produced by temperature alone or in combination with genetic differences. The duration of temperatures favorable for growth increases from north to south. Kramer and Smith (1966) found that the growth of largemouth bass in Lake George, Anoka County, Minnesota, correlated with temperature. The present study demonstrates that the growth rate of bass is retarded at low temperatures and accelerated at high temperatures.

Experiments designed to test the effect of temperature on the growth of bass fry were performed as a part of Project No. 111 at the Texas Agricultural Experiment Station, Department of Wildlife Management, at the A. Wood State Fish Hatchery, San Marcos, Texas, and supported financially by the Texas Game and Fish Commission under an interagency contract with the Texas Agricultural Experiment Station. The fry were hatched and raised in waterbaths maintained at 15.0, 17.5°, 20.0°, 22.5°, 25.0°, 27.5°, and 30.0°.

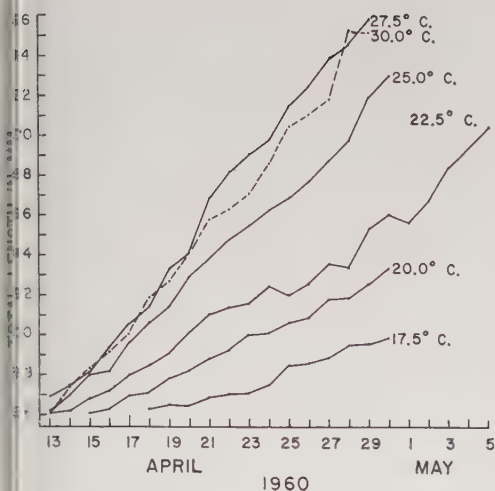


FIGURE 1.—Growth rates of largemouth bass fry at various temperatures.

Temperatures varied less than $\pm 0.1^\circ \text{C}$. except that unexpectedly high ambient temperatures caused some daytime rises of as high as 0.5° at 20.0°C . and as much as 1° at 17.5°C . The waterbaths were plywood boxes lined with 1-inch polyurethane foam insulation obtained from the American Latex Products Corporation. One inch of polyurethane insulation, K factor of less than 0.15, is equivalent to about 2 inches of corkboard, K factor of 0.285. The waterbaths were coated with polyester resin. Inside dimensions of the boxes were 30 inches long, 16 inches wide, and 18 inches deep. The inside bottom of each waterbath was covered with 4 inches of fine river gravel, and undergravel water filters of the type made for home aquaria were used.

Eggs that had started to hatch were taken from a nest in a hatchery pond on April 8, 10, and placed in aerated gallon jars which floated in the waterbaths. When the fry became free swimming, they were turned loose in the waterbaths in which the jars had been floating. Plankton, consisting mostly of cladocerans, netted in the hatchery ponds was fed with the fry at all times. The fry raised at 30.0°C . and 27.5°C . had been feeding between 1 and 2 days when the first samples were preserved. The first samples of fry raised at temperatures below 27.5°C . were preserved the day that the fry started feeding. Feeding begins when the fry rise above the nest and become free-swimming. Every night a sample of 10 fry from each temperature was

preserved in 5-percent formalin. Miscounts of the number of fry put into the preservative and accidental desiccation of fry stranded above the preservative resulted in two samples of 8 fish and one of 12. The first samples of fry were captured with a pipette. As the fry increased in size, they became difficult to capture with a pipette, and a small dip net was used for sampling. The samples probably contain some bias for undersized fish because the slower-growing fry tended to stay near the surface where they were easily caught. Their normal siblings lived at greater depths in the waterbaths and were less available.

At 15.0°C . eggs hatch and fry rise from the nest, but few of them feed. None of over 300 fry hatched at this temperature fed and all died of starvation. Minimum temperature at which Texas fry will feed appears very close to the minimum spawning temperature, 15.9°C . (Kramer and Smith, 1960). Growth rate of the few fry from other nests that were hatched and raised at 15.0°C . was very slow. Growth rate increased with an increase in temperature (Figure 1). Maximum growth occurred at 27.5°C . and 30.0°C . Gibson and Hirst (1955) found the optimum temperature for growth of pre-adult guppies, *Lebistes reticulatus* (Peters), to be in the neighborhood of 23° to 25°C . They grew more slowly at 20° , 30° , and 32°C . Largemouth bass also grow more slowly at high temperatures. Fry from another nest, hatched at temperatures below 30.0°C . and raised at 32.5°C ., grew more slowly than fry (Figure 1) raised at 25.0° and 30.0°C . Eggs put directly into water at 32.5°C . died.

The fish raised at 22.5°C . grew more slowly than expected during the latter part of the experiment (Figure 1). This slower growth rate probably was caused by crowding. The 22.5°C . lot consisted of 1,032 fish when poured into the waterbath. The other lots contained 248 to 422 fry.

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Louver Efficiency in Deflecting Downstream Migrant Steelhead

A louver facility constructed early in 1960 in Maxwell Irrigation Canal, Umatilla River, Oregon, proved very effective in deflecting immature migrating steelhead. The principles of employing louvers to deflect fish were originally studied and demonstrated to be of practical application at the Tracy Pumping Plant near Tracy, California (Bates and Vinsonhaler, 1957; Bates, Logan, and Pesonen, 1960). The Maxwell installation has demonstrated that the principles incorporated in the Tracy structure for deflecting chinook salmon and striped bass in a canal with a total flow capacity of 5,000 c.f.s. are equally applicable for deflecting young steelhead in a canal with a maximum flow capacity of 100 c.f.s.

The installation had the double purpose of serving as an experimental facility and of providing an economical means of diverting steelhead from the irrigation system served. It included both a vertical and a horizontal louver section. Study of the horizontal louver section provided information of value, but since the depth of the canal precluded a satisfactory evaluation of its effectiveness for diverting young steelhead, it is not discussed at length in this report.

THE FACILITY

Figure 1 shows the major features of the louver installation and is largely self-explanatory. Since hydraulic conditions must be provided that insure smooth flow for proper operation of louvers, a concrete-lined canal section was constructed upstream from existing control gate. This concrete section is 15 feet wide, 5 feet deep, and 50 feet long. The irrigation canal was widened along the concrete section by approximately 15 feet to permit diversion of all irrigation flow around the entire structure during periods when modifications were made within the louver structure.

The vertical louver facility was placed at a 20° angle to the direction of flow. The length of the louver line was 30 feet and height 5 feet. Slope of the horizontal louver facility to the canal floor was approximately 15°. Along the line of louvers and starting at the canal floor, the louver slats were stalled with 1-inch clear spacing for the first 9 feet and at 0.5-inch clearance for the remaining, or uppermost, 3 feet of the downstream end. For both facilities, fish passing into the bypass system were carried by separate conduit through the left bank canal wall

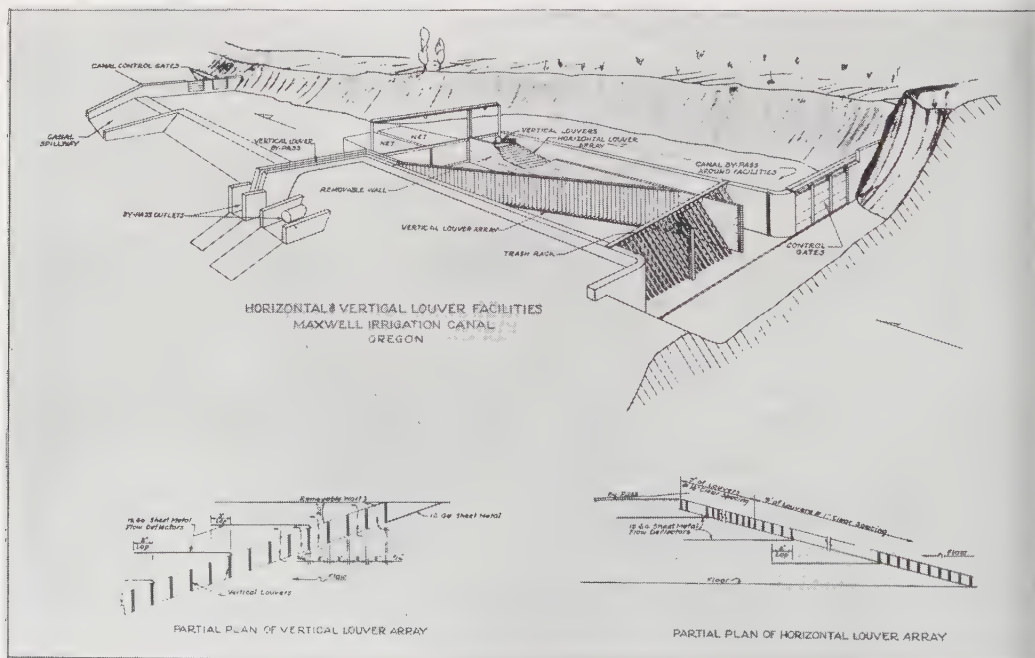


FIGURE 1.—Horizontal and vertical louver facilities, Maxwell Irrigation Canal, Oregon.

TABLE 1.—Influence of louver slat spacing and of approach velocity on efficiency of vertical louvers deflecting young steelhead¹

Approach velocity (ft per second)	Spacing (inches)	Fish through bypass (number)	Fish through louvers (number)	Efficiency (percent)
0.3	2	402	8	98.0
0.7	2	596	12	98.0
1.6	2	1,122	16	98.6
2.6	2	508	8	98.4
0.9	4.25	44	2	95.6
1.4	4.25	642	28	95.8
1.6	4.25	2,265	232	90.7
1.6	10	188	113	62.6

¹Louver line placed on a 20° angle to flow; mean fork length of fish 7.6 inches.

an inclined screen fish trap attached to the discharge end of each bypass.

To determine the numbers of fish which might pass through the louvers during any time period, nets were installed at the downstream end of each of the two canals. The nets were hung on steel frames which in turn were held in position by guide slots. Hoists for lowering and raising the nets were operated manually.

RESULTS

To eliminate any question that the nets captured all fish which passed through the louver array, electrical fish-shocking equipment was utilized. At the conclusion of each test the entire area immediately downstream from the louvers and into the net entrances was shocked. After employing this technique for a 2-week period and finding no fish, shocking was terminated.

Table 1 summarizes the results of a series of tests to determine the efficiency of the vertical louver installation under several operating conditions. While slat spacing of 2 inches proved most efficient, very good results were also obtained with a 4.25-inch spacing. Even with a 10-inch spacing, over 60 percent of the young steelhead approaching the array were deflected. No significant difference in efficiency was found within the range of approach velocities tested.

While it is evident that a louver installation is feasible for immature, migrating steelhead under the physical conditions that exist at Maxwell Canal, there are two major limitations that should be noted when results obtained with the two types of louver installations tested are judged. Debris handicapped louvering operations so that the duration of fish-trap time was not constant in all of the tests.

The abundance of downstream migrant steelhead varied greatly and at times was so low that tests could not be conducted.

CONCLUSIONS

On the basis of one season's operation of the louver installation at Maxwell Canal, the following conclusions appear warranted: (1) application of louver principles for deflecting downstream migrant steelhead proved successful; (2) a vertical louver installation was very effective in deflecting downstream migrant steelhead; and (3) physical conditions precluded an adequate trial of the efficiency of a horizontal louver installation.

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Gill-Net Selectivity of Lake Whitefish from Goderich-Bayfield Area, Lake Huron

In a report on the analysis of gill-net selectivity for lake whitefish (*Coregonus clupeaformis*) made at the South Bay Fisheries Station, McCombie and Fry (1960) pointed out that one application of the results might be in the evaluation of mesh-size regulations. The purpose of the present paper is to show how such an evaluation might be made in an actual case. The demonstration is based on a sample of 1,639 whitefish taken from commercial catches made in the Goderich-Bayfield region of Lake Huron during April 1960. Since the fish were not selected for size, the composition of this sample presumably reflects that of the entire catch.

It is evident from consideration of the age and size composition of the sample (Table 1) that one age group and one size class predominate. Ninety-three percent of the fish are age-group III, and 63 percent have a fork

TABLE 1.—Length and age composition of catches of whitefish (*Coregonus clupeaformis*) taken in the Goderich-Bayfield area of Lake Huron during April 1960

Fork length (inches)	[Percentage of total in parentheses]				Total number
	II	III	IV	V	
12.0–12.9	8	—	—	—	8
13.0–13.9	14	1	—	—	15
14.0–14.9	2	6	—	—	8
15.0–15.9	—	305	2	—	307
16.0–16.9	—	1,024	8	1	1,033 (63)
17.0–17.9	—	194	13	—	207
18.0–18.9	—	5	34	—	39
19.0–19.9	—	—	17	—	17
20.0–20.9	—	—	2	1	3
21.0—	—	—	—	—	2
Total number in sample	24	1,535 (93)	76	4	1,639

length of 16.0–16.9 inches. The absence of smaller fish is readily accounted for by the relatively large mesh size used (4¾ inches stretched measure, knot to knot), but the cause of marked scarcity of larger, older fish is not apparent. It may be that the few larger fish taken belonged to weak year classes. On the other hand, the situation resembles that found in the North Channel fishery during the past 2 years, where the lamprey appears to be making a serious reduction in the larger fish.

To determine how efficiently the fishermen are harvesting the Goderich-Bayfield whitefish with their present gear and to estimate the probable effects of a reduction in mesh size, one proceeds as follows.

The girth datum for the midpoint of each length class of whitefish considered is read from the regression line in Figure 1 and tabulated in the second line of Table 2. The line

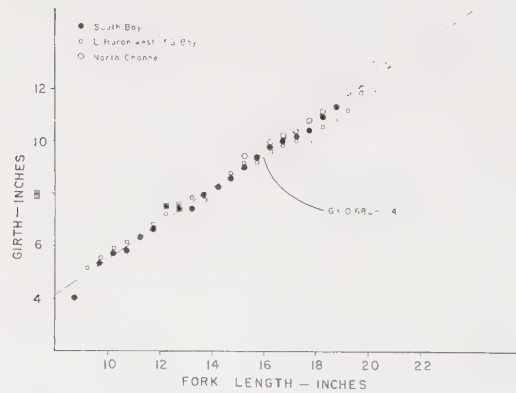


FIGURE 1.—Relationship of fork length to girth of whitefish from South Bay, North Channel, and Lake Huron west of South Bay.

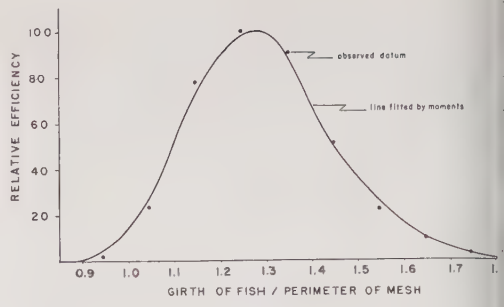


FIGURE 2.—Selectivity of gill nets for South Bay whitefish.

is fitted to data for South Bay whitefish by the data available from the North Channel and from Lake Huron west of South Bay indicates that the girth-to-length relations for the latter populations are quite similar to those of the South Bay fish (open circles and squares in Figure 1). Since the Goderich-Bayfield area is also a part of Lake Huron, it is assumed for the present that the same girth-to-length relation holds for whitefish from that location.

The successive girth data are then divided by the perimeter of the mesh under consideration (in this case the 4¾-inch mesh), and the quotients are entered in the third line of Table 2. The third step refers each girth-to-perimeter ratio to the selectivity curve in Figure 2 to obtain the corresponding ordinate, which is then entered in the fourth line of Table 2. This figure is the same as Figure 4 of McBride and Fry (1960), except that the ordinates have been expressed as percentages of the modal ordinate, which has been assigned an arbitrary value of 100. The datum points in the figure were derived from the analysis of catches taken from South Bay with experimental gangs of gill nets during the years 1954–58. A probability curve has been fitted to these points by the method of moments described by Croxton and Cowden (1959) using the parameters mean, standard deviation, and a measure of skewness (α_3), which are respectively 1.2928, 0.1473, and 0.4449. Each ordinate of this curve represents the relative frequency or efficiency with which a fish of given girth would be caught in a mesh of stated perimeter.

From the efficiency estimates (Table 2) it is evident that the capacity of the 4¾-inch mesh to capture fish of the 16.0–16.9-inch class is only about half its capacity to take 17.0–17.9-inch fish. The mesh size presently in use, therefore, would appear to be comparable

TABLE 2.—*Procedure for estimation of relative efficiency of capture of whitefish of different length classes by various gill-net meshes*

[Perimeter (P) of 4.75-inch stretched measure mesh = 9.5]

Length (inches)	12-12.9	13-13.9	14-14.9	15-15.9	16-16.9	17-17.9	18-18.9	19-19.9	20-20.9
(C) ¹	7.1	7.8	8.5	9.2	9.8	10.5	11.2	11.9	12.5
	0.75	0.83	0.89	0.98	1.03	1.10	1.18	1.27	1.32
Relative efficiency of capture ²	0	0	0	10	23	53	82	99	95

¹The girth datum for the midpoint of each length class was obtained from the girth-to-length function derived from samples of whitefish from South Bay, Manitoulin Island.

²Read from Figure 2.

ly inefficient in harvesting whitefish of the size predominating in the Goderich-Bayfield area during 1960.

By making the required changes in perimeter and consequently in the girth-to-perimeter quotients, three more series of efficiency statistics can be obtained from the selectivity curve, corresponding to $4\frac{1}{2}$ -, $4\frac{3}{4}$ -, and 4-inch meshes. These statistics have been compared with the efficiencies for the $4\frac{3}{4}$ -inch mesh (Table 3) to show the probable consequences of successive quarter-inch reductions in mesh size.

The data for 16.0-16.9-inch fish (Table 3) are particularly important. They indicate that a successive quarter-inch reduction in mesh size would increase the relative efficiency of the net by about 25 percent. Moreover, if the statistics for 16.0-16.9-inch fish are compared with those for 20.0-20.9-inch fish, it is found that a change in mesh size from $4\frac{3}{4}$ to 4 inches could simply reverse the efficiency with which the two sizes of fish are taken. A reduction of $\frac{1}{4}$ -, $\frac{1}{2}$ -, or even $\frac{3}{4}$ inch in mesh size therefore could make the harvest of Goderich-Bayfield whitefish considerably more efficient, should it prove to be desirable in view of lamprey infestation.

Conversely, the data for fish 12.0 to 14.9 inches in length (Table 3) show how well the present regulation calling for a $4\frac{1}{2}$ -inch minimum on mesh size protects fish shorter than

16.0 inches. If it were desirable to conserve such fish as future spawning stocks, such selection would be very significant. The relative efficiency of capture of fish 15.0-15.9 inches long would be 21 percent and that for still shorter classes would be negligible. It is also evident that a $4\frac{3}{4}$ -inch minimum mesh size would be still more effective in excluding the smaller fish.

The efficiency statistics discussed here indicate only the proportion of fish which one mesh will capture relative to other meshes. They do not show directly what fraction of the available fish any mesh will catch. The latter fraction would have to be computed from tag returns or other methods of population estimation.

The foregoing considerations demonstrate a practical application of gill-net selectivity studies in fisheries management. They indicate the relative efficiency with which the present gear harvests various sizes of whitefish and the marked increase in fishing intensity which would probably result from comparatively small reductions in mesh size. Whether changes in mesh size are desirable or not will depend, however, on the particular biological conditions prevailing in the area under consideration.

I am indebted to J. C. Budd of the South Bay Fisheries Station for suggesting that this paper be prepared and making the data avail-

TABLE 3.—*Relative efficiencies of capture of different size classes of whitefish by gill nets of various meshes*

Length (inches)	12-12.9	13-13.9	14-14.9	15-15.9	16-16.9	17-17.9	18-18.9	19-19.9	20-20.9
Number in sample	8	15	8	307	1,033	207	39	17	3
Mesh (inches) ¹									
4.75	0	0	0	10	23	53	82	99	95
4.50	0	0	4	21	48	77	97	73	45
4.25	0	0	15	43	76	95	95	67	42
4.00	0	10	34	73	95	97	67	39	22

¹Stretched measure.

able and to D. Cucin of the South Bay Station who carried out the sampling of the Goderich-Bayfield whitefish catches.

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REVIEWS

Traité de Pisciculture. By Marcel Huet. Third edition. Ch. De Wyngaert, Bruxelles. 1960. 369 pp., 280 figs. \$9.00.

Traité de Pisciculture by Dr. Marcel Huet, Director of the Research Station of Waters and Forests of the Belgian Ministry of Agriculture and Professor at the University of Louvain, was first published in 1911 and has now reached its third edition. This is sufficient evidence that the book has become a landmark in its field. It is known for its comprehensiveness, logical presentation, clarity of writing, and excellent illustrations. European engraving is outstanding compared with ours, and the quality of the figures in Dr. Huet's book is not disappointing. These photographs and line drawings are reproduced exceptionally well.

The *Traité de Pisciculture* can be described in general terms as a handbook patterned after the American style. Its treatment is also dominantly European. Very little attention is given fish culture in North America or other parts of the world, with the exception of an extremely interesting account of fish culture in tropical Africa. Dr. Huet represented the Belgian government in the Congo on several fish-cultural missions before the independence of that country.

The third edition has been changed very little from the second. The two most important differences are found in the revisions of the sections dealing with fish culture and the control of aquatic vegetation. A brief review of the contents is given for those unfamiliar with the book. The details of construction and management of ponds is followed by chapters on natural and artificial feeding, the culture of carp, trout, pike, coregonines, bass, and eels. The last two chapters deal with productivity and pond stock-maintenance and improvement of ponds, and the handling and transport of fish. North Americans will find the chapter on carp culture especially interesting. Dr. Huet reviews the major European types of culture which have reached unusual finesse as a result of generations of experience in breeding and rearing fish for food.

Each topic is discussed thoroughly. The chapter on trout culture may be taken as an example. The requirements of pond culture of trout are given; the histories of brook, brown, and rainbow trout are briefly discussed; and a detailed treatment is presented of culture from the egg to the end-product which includes incubation, hatching, and rearing of young with and without supplemental feeding. There is a sprinkling of ideas about pond ecology, and as a whole the book can be classed as a manual of tested methods of European fish culture. No emphasis is placed on fish diseases. There is no index, but the table of contents is very complete and sufficient for easy reference.

Some may wish to add this reference to their personal collection, but all should recommend it for their library by their most convenient library. Graduate students should by all means be encouraged to read the book in preparation for their French examinations. They will learn a great deal and discover that the writer is a master of logical and concise writing.

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Living Fishes of the World. By Earl S. Herald. Doubleday, Garden City, N. Y. 1961. 304 pp., 155 halftones, 145 full-color illustrations. \$12.50.

This is by far the best compendium we have seen of fish illustrations. The book (8½- by 11-inch pages) is printed on high-quality gloss paper. Illustrations are made as large as possible by "bleeding" off the edge of the page, as well as by spreading many onto two pages. Action pictures of fish in natural surroundings are numerous and of extraordinary quality.

As in any attempt to cover such a large subject in small compass, only the most salient and interesting life-history points are discussed for each family. Written in a style easily understood by the layman, the text is, at the same time, so full of facts about each group that one finds it hard to set the book aside. The price is not high considering the quality and number of illustrations. The phylogenetic arrangement and index to both common and scientific names render it valuable as a general reference. This book is highly recommended for your library.

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Fishery Management. By R. S. Fort and J. D. Brayshaw. Faber and Faber, London. 1961. 398 pp., 82 figs., 17 pl. 45s.

The title of this book is rather misleading; a more accurate title would be *Management of British Streams with Special Emphasis on Salmon*. The audience to which this book is apparently addressed scarcely exists in the United States. The book is far too detailed and specific for the lay reader and lacks the technical accuracy required by the scientist. The audience appears to be the large number of enthusiastic amateur sportsmen who can afford the luxury of salmon angling. Examples of technical errors: on page 13, "In theory a pond may produce enough fish food to support 100 fish weighing 1 lb. each or 400 fish weighing ¼ lb. each," and on page 47, "A. Salmonids. This family includes salmon, sea trout, brown trout, rainbow trout, char, whitefish, grayling and sparring [smelt]." On page 218 the Deep Channel Fishpass which his diagram shows as the deep-baffle type used in the United States and Canada is described as being adapted for "... very high obstructions. . . ."

A large share of the book is devoted to British fresh-water fishery laws and administration, a non-technical discussion of stream pollution, methods of stream improvement, and diagrams and pictures of many bizarre means of catching a salmon, perhaps the oddest being a large wicker funnel so long and narrow at the small end that the entering salmon becomes jammed and cannot back out. The style is entertaining, and if you wish to build a small foot-bridge or a fishing shelter, the details are given. The droll style is best illustrated on page 251, "... when cutting through a branch from a ladder, the cut should be made on the side of the ladder away from

the trunk." For British anglers the detailed material on the functioning of the River Boards should be rewarding.

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ecologist to absorb the lessons learned or unlearned by the problems posed in this paper.

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RECENT PUBLICATIONS

BACTERIAL ACTIVITY IN SEDIMENTS OF SHALLOW MARINE BAYS. By Carl H. Oppenheimer. In *Geochimica et Cosmochimica Acta*, Vol. 19, pp. 244-260, 1960. 8 figs., 4 tables, Pergamon Press Ltd., London.

In addition to briefly discussing shallow bay sediments this paper presents a review of some of the pertinent literature concerning ecological aspects of bacteria in the marine environment, and more significantly it directly and indirectly exposes some of the difficult and intricate problems associated with marine ecological investigations and understanding. In his discussion of organic matter, source, and diagenesis in the bay environment the author points out, possibly too briefly, some of the factors involved in the distribution of organic matter in sediments, i.e., living organisms, particulate material, and scavenging of dissolved material. This latter point should be stressed since such a mechanism may well be a major contributing factor for organic distribution where appreciable available surface area is present as in fine-grained sediments.

The difficult problems concerning absolute bacterial counts are also discussed. All individuals investigating ecological systems with respect to sediments must be aware of these limitations which are due to technique difficulties.

Concerning the rate of decomposition of organic matter, the writer contends that organic decomposition is more rapid in sands than in clays due to the more abundant types of bacteria present in sands. In this statement we find one of the anomalies or conflicts related to sediment organic geochemistry or biogeochemistry. Particle size, mineralogy, organic matter, bacteria, decomposition rates, etc., may all be considered separate for some purposes yet their interrelationship must be equally understood before we can arrive at an understanding of the operative ecological situation. This conflict is further demonstrated when the author discusses bacteria and particle size.

The writer also points out the problem of organic material present and organic material available. This is a vital concept in that the mere presence of organic material does not of necessity mean the presence of a nutrient source. The pH and redox potential discussion also briefly demonstrates the complexity of the situation. Both are extremely difficult to determine with a uniform degree of usefulness. There can well exist an appreciable difference between the values obtained by measurement and the actual operative conditions.

In summary this paper is quite valuable in that it attempts to point out the severe difficulties which are inherent in our investigations of sedimentary chemistry and biochemistry. It is necessary for the

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